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Original Article

Quantitative Analysis of Epicardial Adipose Tissue: 120K Shades of Heart

Yasir Jan[1], Azam Jan[2]*, Wahaj Ayub[3], Muhammad Wasim Sajjad[4], Rashid Qayyum[5], Hafiz Hammad Sharafat Satti[6]

[1]Senior AI Consultant, Sir Syed Case Institute of Technology, Pakistan.
[2]Professor and HOD, Cardiothoracic Surgery- Rehman Medical Institute, Peshawar, Pakistan.
[3]Research Assistant and Rotational Training Medical Officer- Cardiothoracic Surgery- Rehman Medical Institute, Peshawar, Pakistan.
[4]Resident Cardiac Surgeon, Rehman Medical Institute, Peshawar, Pakistan.
[5]Research Officer, Cardiac Surgery Department- Rehman Medical Peshawar, Pakistan.
[6]Student, Sir Syed Case Institute of Technology, Islamabad, Pakistan.
Corresponding Author: Azam Jan, Professor; Email: azam.jan@rmi.edu.pk

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ABSTRACT

Background: Epicardial adipose tissue (EAT) is the fat deposited between the myocardium and epicardium. Due to its unique anatomical position, EAT has both protective and harmful effects on the heart, influencing conditions such as coronary artery disease, atrial fibrillation, and heart failure. This study aimed to quantify the amount of EAT by analyzing the color shades of the heart's anterior surface during coronary artery bypass grafting (CABG) procedures.

Objective: To assess the number of color shades in different sub-regions of the heart and quantify EAT using real-time 2D images captured during CABG procedures, and to correlate these findings with clinical conditions and risk factors.

Methods: The study was conducted at Rehman Medical Institute, Peshawar, from October 2023 to April 2024. Images were captured using an iPhone 11 with a 12-megapixel camera during CABG procedures, specifically before cannulation, after opening the pericardium, and tucking the pericardium to the skin on a beating heart. Photographs were taken at a 90-degree angle and one-foot distance during systole, including surrounding tissues and a self-retaining retractor with a ruler for measurement reference. The images from three patients were processed to form the "HEART ANTERIOR VIEW THROUGH STERNOTOMY (HATS)" dataset. The data were cleaned and standardized for consistency. The surgical team annotated and labeled the images using the LabelMe tool, identifying the full heart region and its sub-regions: Aorta, Right Ventricle (RV) Myocardium, RV and Pulmonary Artery (PA) Epicardial Fat, and Right Atrium (RA) Appendage. Image segmentation techniques isolated the heart region and identified fat deposits. The total area of fat on the anterior surface of RV, PA, and RA was quantified using appropriate algorithms. Pixel analysis was conducted to determine the color shades, with each pixel having three color channels (Red, Green, Blue) and 256 intensity values per channel.

Results: The total pixel count for the full image (heart and surrounding region) was 1600x1200 for Patient 1, 480x624 for Patient 2, and 480x848 for Patient 3. The heart regions contained 218,864 pixels (Patient 1), 44,020 pixels (Patient 2), and 77,919 pixels (Patient 3). The EAT areas were found to be 158,213 pixels (Patient 1), 35,608 pixels (Patient 2), and 52,723 pixels (Patient 3). The percentage areas of the sub-regions varied, with RV and PA Epicardial Fat comprising 72.3%, 80.9%, and 67.7% of the heart regions for Patients 1, 2, and 3, respectively. The top 100 color shades were identified, with unique colors in the Aorta (23,323), Appendage (7,030), Epicardial Fat (80,257), and Myocardium (10,131).

Conclusion: The study demonstrated that EAT and the color shades of heart sub-regions could be accurately quantified using advanced imaging and computational techniques. These findings provide valuable insights into the correlation between EAT and cardiac risk factors, enhancing the ability to predict postoperative morbidity and mortality and enabling early interventions to improve patient outcomes.

Keywords: Epicardial Adipose Tissue, EAT Quantification, Coronary Artery Bypass Grafting, CABG, Heart Imaging, Cardiac Risk Factors, Color Shade Analysis, Myocardium, Aorta, Pulmonary Artery, Right Atrium, Medical Imaging, Cardiovascular Health, Postoperative Outcomes, Image Segmentation, Pixel Analysis.

Journal of Health and Rehabilitation Research 2791-156X JHRR

INTRODUCTION

In the operating theatre, as surgeons, the visual appearance of the heart often provides critical clues to its health. This observation prompted an analysis of the heart's anterior surface during coronary artery bypass grafting (CABG) procedures, utilizing computer technology to examine detailed images of the beating heart. A key feature of interest is the epicardial adipose tissue (EAT), which, as established, can have detrimental effects on cardiac health. Our objective is to quantify the EAT using color shades, despite the lack of existing literature specifically addressing the color variations of the heart. However, there is a growing body of research focused on EAT (1).

Epicardial adipose tissue, situated between the myocardium and the epicardium, has unique anatomical characteristics that confer both beneficial and adverse effects. Its proximity to the heart allows it to perform protective functions, such as dynamic brown fat-like thermogenic activity (2-3). Conversely, EAT can also contribute to harmful outcomes through the secretion of pro-inflammatory cytokines. Notably, EAT associated with coronary arteries and the left atrium is implicated in the pathogenesis of coronary artery disease and atrial fibrillation, respectively, and it also plays a role in heart failure development (1). Importantly, EAT is a modifiable risk factor, controllable through exercise and medications, and assessable via CT scan (2). Genetic, epigenetic, and environmental factors can drive the transition of EAT towards a dysfunctional state. Beyond paracrine secretion, EAT may directly release mediators into the vasa vasorum, a process known as vasocrine secretion, which actively contributes to coronary atherosclerosis development. Dysfunctional EAT releases pro-inflammatory and pro-fibrotic cytokines that impair cardiac structure and function (2).

Furthermore, dysfunctional EAT plays a role in the recurrence of atrial fibrillation following ablation procedures (3). It also contributes to conduction abnormalities. Elevated local EAT volumes are linked with slowed conduction, increased electrogram fractionation, heightened fibrosis, and lateralization of cardiomyocyte connexin-40. Cardiac culture studies have shown that factors secreted by EAT can slow conduction velocity and disrupt intermyocyte electromechanical integrity, leading to increased atrial conduction heterogeneity (4). Recent advances in imaging techniques, including echocardiography, CT angiography, and heart CT scans, have enabled the quantification of EAT. Given its significant impact, incorporating EAT assessment into clinical practice could assist clinicians and surgeons in identifying patients at higher risk for cardiovascular, especially coronary artery disease, and metabolic diseases, thereby optimizing therapeutic and surgical interventions (5-7).

MATERIAL AND METHODS

The study aimed to assess the color shades of various sub-regions of the heart and quantify epicardial adipose tissue (EAT) using real-time 2D images captured during coronary artery bypass grafting (CABG) procedures. This research was conducted at Rehman Medical Institute, Peshawar, from October 2023 to April 2024. The images were captured using an iPhone 11 with a 12-megapixel camera during the CABG procedure, specifically before cannulation, after opening the pericardium, and tucking the pericardium to the skin on a beating heart. Photographs were taken from a 90-degree angle and a distance of one foot during systole. These images included surrounding tissue such as muscles, blood, and skin, as well as a self-retaining retractor and a ruler to aid in measurement. The images collected from the three patients formed the first-ever labeled heart image dataset, named "Heart Anterior View Through Sternotomy (HATS)." The images were then processed and analyzed to detect the percentage of different tissues and epicardial fat on the heart. The processing involved several steps: data cleaning and standardization to ensure consistency and accuracy; annotation and labeling by the surgical team, who identified the full heart region and its sub-regions (Aorta, Right Ventricle Myocardium, Right Ventricle and Pulmonary Artery Epicardial Fat, and Right Atrium Appendage) using a labeling tool called LabelMe; and image segmentation techniques to isolate the heart region and identify fat deposits. The total area of fat on the anterior surface of the Right Ventricle, Pulmonary Artery, and Right Atrium was quantified using appropriate algorithms (8-11).

The images consisted of numerous pixels, each representing the smallest portion of an image, measured in pixel width x pixel height x channel. For example, a 512 x 1024 x 3 image contains 512 rows and 1024 columns of pixels, with each pixel having three color channels. The full image resolution may be 512 x 1024, but the area of the full object or its region will be an irregularly shaped subset of the full image. The irregularly shaped subset region was marked with a rectangular bounding box, allowing the calculation of the maximum width and height of the region.

Each pixel had three color channels: Red (R), Green (G), and Blue (B), each with 256 intensity values ranging from 0 to 255. Using a combination of the R, G, and B intensities, 256 x 256 x 256 possible shades could be created. For instance, a pixel shade could be represented as (0, 10, 230), indicating Red intensity = 0, Green intensity = 10, and Blue intensity = 230. These values could also be represented using hexadecimal numbers, such as #01A045 for RGB (1, 160, 69). The heart images were processed to extract a list of all color shades from various regions in the image.

Journal of Health and Rehabilitation Research 2791-156X JHRR

Data collection adhered to ethical standards outlined in the Declaration of Helsinki. All patients provided informed consent prior to participation. The data analysis involved statistical techniques to quantify the EAT and assess its distribution across different heart regions. The analysis included the use of descriptive statistics and image processing algorithms to determine the percentage and area of EAT. The results were reported using both decimal and hexadecimal color representations to ensure clarity and accuracy in identifying the color shades associated with different tissues.

This study's methodology provides a novel approach to evaluating EAT through the analysis of color shades in heart images, potentially offering new insights into the assessment and management of cardiovascular health. The findings could help clinicians and surgeons identify patients at higher risk for cardiovascular diseases and optimize therapeutic and surgical interventions (1, 2, 3, 4, 5).

RESULTS

The study's results demonstrate significant variability in the epicardial adipose tissue (EAT) and the color shades within different heart sub-regions across the three patients analyzed. The total pixel count for the full image, which includes the heart and surrounding regions, varied notably among the patients. For Patient 1, the full image resolution was 1600x1200 pixels, encompassing a total of 218,864 pixels within the heart region. This included 32,348 pixels for the Aorta, 17,870 pixels for the Right Ventricle (RV) Myocardium, 158,213 pixels for the RV and Pulmonary Artery (PA) Epicardial Fat, and 10,433 pixels for the Right Atrium (RA) Appendage (Table 1). In contrast, Patient 2's full image had a resolution of 480x624 pixels, with 44,020 pixels in the heart region, comprising 6,857 pixels for the Aorta, no pixels for the RV Myocardium, 35,608 pixels for the RV and PA Epicardial Fat, and 1,555 pixels for the RA Appendage. Patient 3's image resolution was 480x848 pixels, with a heart region containing 77,919 pixels, including 17,518 pixels for the Aorta, 7,678 pixels for the RV Myocardium, 52,723 pixels for the RV and PA Epicardial Fat, and no pixels for the RA Appendage.

Analyzing the percentage area of each sub-region of the heart revealed further insights. For Patient 1, the Aorta accounted for 14.8% of the heart region, the RV Myocardium for 8.2%, the RV and PA Epicardial Fat for a substantial 72.3%, and the RA Appendage for 4.8% (Table 2). Patient 2 displayed a slightly different distribution, with the Aorta comprising 15.6% of the heart region, no contribution from the RV Myocardium, a higher percentage of 80.9% for the RV and PA Epicardial Fat, and 3.5% for the RA Appendage. Patient 3 showed a more balanced distribution, with the Aorta representing 22.5%, the RV Myocardium 9.9%, the RV and PA Epicardial Fat 67.7%, and no RA Appendage detected.

The detailed analysis of the color shades in each sub-region of the heart highlighted significant differences in pixel counts across the patients. Patient 1's Aorta displayed 10,621 unique shades, while the RV Myocardium showed 4,516 shades, the RV and PA Epicardial Fat exhibited 48,353 shades, and the RA Appendage had 5,794 shades (Table 3). In comparison, Patient 2's Aorta contained 4,731 shades, with no shades for the RV Myocardium, 18,053 shades for the RV and PA Epicardial Fat, and 1,236 shades for the RA Appendage. Patient 3 exhibited 8,756 shades in the Aorta, 5,968 shades in the RV Myocardium, 24,810 shades in the RV and PA Epicardial Fat, and no shades in the RA Appendage.

These findings underscore the variability in EAT and tissue characteristics across different patients. The analysis of color shades, facilitated by advanced imaging techniques, provided a precise quantification of the EAT in each sub-region of the heart, offering a deeper understanding of its distribution and potential implications for cardiac health. The visual representation of the top 100 color shades from each region, as depicted in Figure 1, further illustrates the diversity in tissue composition and highlights the potential of this methodology for detailed cardiac assessment. By correlating these findings with clinical conditions and risk factors, this study paves the way for improved prediction and management of cardiovascular diseases, leveraging the detailed quantitative data obtained from pixel analysis and color shade differentiation.

Table 1: Total Pixel Count of Anterior View of Heart Full Image

Patient No.	Full Image (Heart + Surrounding Region)	Heart* Region	Aorta	RV Myocardium	RV and PA Epicardial Fat	RA Appendage
1	1600 x 1200	218,864	32,348	17,870	158,213	10,433
2	480 x 624	44,020	6,857	0	35,608	1,555
3	480 x 848	77,919	17,518	7,678	52,723	0

Journal of Health and Rehabilitation Research 2791-156X JHRR

Table 2: Percentage Area of All Four Sub-Regions of the Heart

Patient No.	Aorta (%)	RV Myocardium (%)	RV and PA Epicardial Fat (%)	RA Appendage (%)
1	14.8%	8.2%	72.3%	4.8%
2	15.6%	0%	80.9%	3.5%
3	22.5%	9.9%	67.7%	0%

Table 3: Different Shades of Heart Sub-Regions

Patient No.	Aorta	RV Myocardium	RV and PA Epicardial Fat	RA Appendage
1	10,621	4,516	48,353	5,794
2	4,731	0	18,053	1,236
3	8,756	5,968	24,810	0

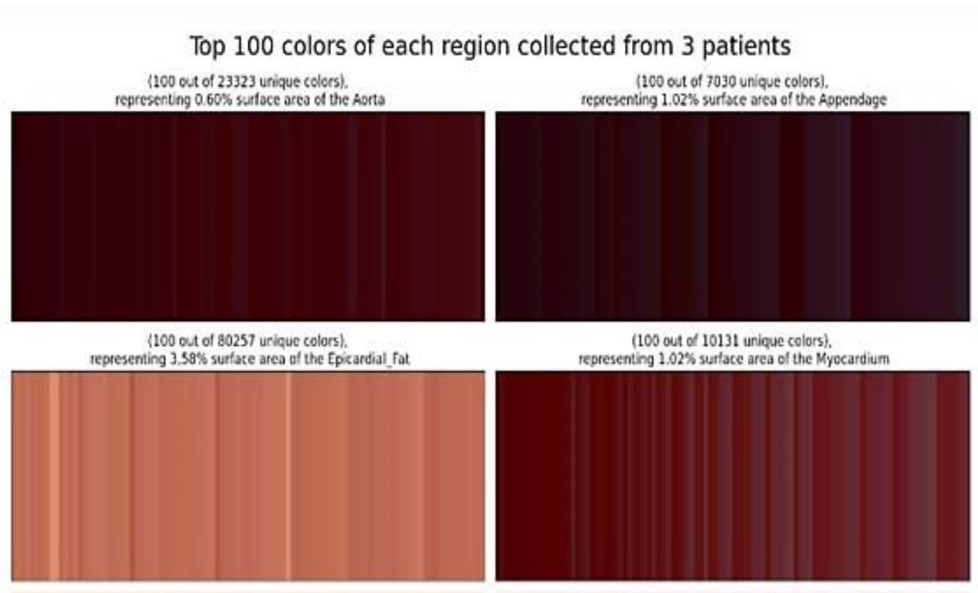

Figure 1 The figure illustrates the top 100 colors sampled from different regions of the heart in three patients. Each panel represents a specific heart region: Aorta (top left), Appendage (top right), Epicardial Fat (bottom left), and Myocardium (bottom right).

DISCUSSION

The human eye cannot distinguish subtle color shades with the naked eye, but a computer can, using various combinations of red, green, and blue color intensities. This study utilized such technological capabilities to obtain data that can be leveraged for multiple purposes, including the precise calculation of the areas of different cardiac subregions, particularly epicardial adipose tissue (EAT) (12-14). By correlating this data with patients' clinical conditions and risk factors such as hypertension, diabetes, extent of coronary disease, serum lipids, and serum creatinine levels, it is possible to gain valuable insights into cardiac health. Previous studies have extensively explored the association between EAT and these cardiac risk factors. For instance, one study investigated the correlation between EAT accumulation and essential hypertension in non-obese adults, finding that EAT thickness and volume were lower in normotensive individuals compared to those with grade 1 and grade 2 hypertension (6). Another study revealed that patients with diabetes and nephropathy exhibited increased EAT, suggesting that EAT assessment could serve as a novel, non-invasive biomarker to identify high-risk patients for cardiovascular events (7). Further research into the relationship between EAT attenuation and coronary artery disease severity in type 2 diabetic patients indicated that these patients had significantly higher coronary artery calcium, coronary plaque prevalence, and segment stenosis scores, alongside increased EAT volume (8).

Additionally, a randomized controlled trial on male swine examined the pathophysiological role of oxidized cholesterols in epicardial fat accumulation and cardiac dysfunction. The study found that a high caloric diet (HCD) led to increased epicardial fat thickness and cardiac dysfunction, which were mitigated by treatment with ezetimibe, a cholesterol absorption inhibitor. This suggested that increased oxycholesterols in the HCD group were closely related to cardiac dysfunction and epicardial fat accumulation (9). These findings collectively indicate that the amount of EAT and associated cardiac risk factors significantly impact patients' morbidity and mortality. By understanding these associations, clinicians can better predict postoperative outcomes and implement early interventions to prevent future adverse effects (15).

Journal of Health and Rehabilitation Research 2791-156X JHRR

However, this study was a pilot involving only three patients, which limits the generalizability of the findings. Further research with a larger patient cohort and an improved model is necessary to validate these results and predict morbidity and mortality in cardiac surgery patients more accurately (16-19). Despite these limitations, the study successfully demonstrated that different patients exhibit varying amounts of epicardial fat tissue and multiple shades of heart color in sub-regions of the heart. The use of color shades allowed for the accurate detection and quantification of each specific tissue type, providing a novel approach to assessing cardiac health. The findings underscore the potential of integrating advanced imaging and analytical techniques into clinical practice to enhance the assessment and management of cardiovascular diseases, ultimately improving patient outcomes (20).

CONCLUSION

In conclusion, the study demonstrated that varying amounts of epicardial adipose tissue (EAT) and multiple color shades in heart sub-regions can be accurately detected using advanced imaging and computational techniques. This method allows for precise quantification of cardiac tissues, providing valuable insights into the correlation between EAT and cardiac risk factors such as hypertension and diabetes. The implications for human healthcare are significant, as this approach could enhance the ability to predict postoperative morbidity and mortality, enabling early intervention and tailored treatments to mitigate cardiovascular risks and improve patient outcomes.

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Journal of Health and Rehabilitation Research 2791-156X JHRR

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