Volumetric Quantification of Regional Adiposity in Miniature Swine Using Segmented CT Data

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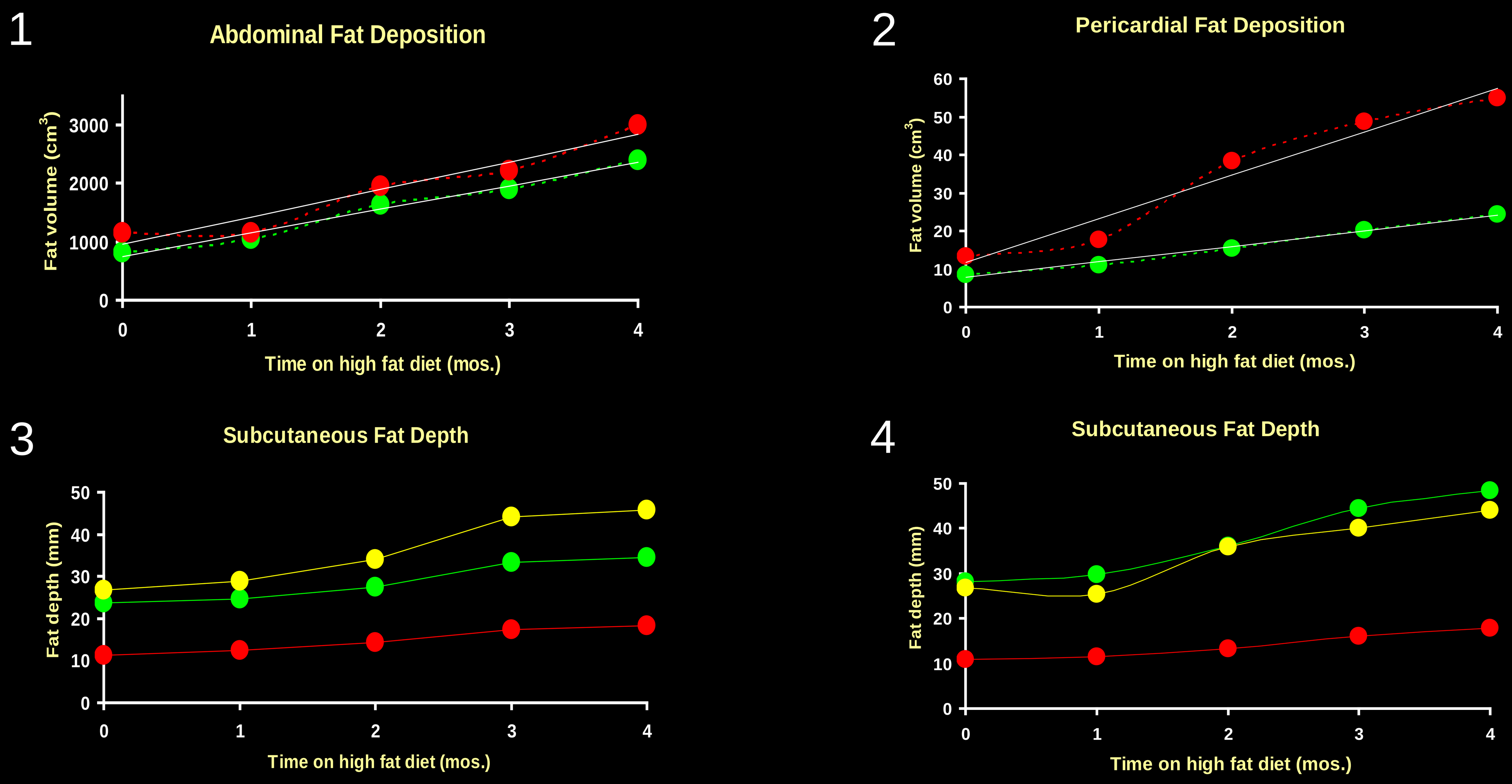
Introduction

Sinclair miniature swine (minipigs) have been used extensively as models for cardiovascular, dermatology, oncology, and obesity research. Our goal was to perform a pilot study using two purpose-bred, castrated male minipigs (approx. 7 months old and 30 kg) fed a high fat diet for 16 weeks to assess regional adiposity changes over time using CT imaging and segmentation of the image data. Previously, fat composition has been measured using dual-emission X-ray absorptiometry (DXA) or by estimating adiposity from a single axial CT image. However, both of these techniques have limitations, and neither is capable of quantifying regional adiposity in a subject. To address this, serial CT imaging of two pigs was carried out at initiation of the high fat diet and every month thereafter for a total of 4 months. Upon completion of the scans, manual segmentation of the CT image data was performed on both pigs to determine the change in pericardial and abdominal adiposity as a function of time.

Figure 1: Anesthesia was induced with ketamine 10 mg/kg and midazolam 0.4 mg/kg *iv* and tracheal intubation performed. Pigs were maintained on inhaled isoflurane/oxygen in sternal recumbancy for acquisition of whole-body CT images.



	Pig 1					Pig 2				
	Subcutaneous fat depth (mm)			Fat volume (cm^3)		Subcutaneous fat depth (mm)			Fat volume (cm^3)	
Month	Center	Left	Right	Abdominal	Pericardial	Center	Left	Right	Abdominal	Pericardial
0	11.3	23.7	26.8	812	9	10.9	28.2	26.7	1159	13
1	12.5	24.5	28.8	1040	11	11.5	29.8	25.4	1160	18
2	14.3	27.5	34.0	1629	15	13.3	36.1	35.9	1958	38
3	17.3	33.3	44.0	1910	20	16.0	44.4	40.1	2213	49
4	18.3	34.5	45.8	2396	24	17.9	48.5	44.0	3000	55

	Abdominal fat		Pericardial fat	
	Pig 1	Pig 2	Pig 1	Pig 2
Rate (cm^3/mos.)	47.4	40.4	11.4	4.1
R^2 (linear regression)	0.931	0.984	0.955	0.99

Figure 3: Graphs 1 and 2 depict the linear correlation between exposure to a high fat diet and abdominal or pericardial fat deposition for both pig 1 (green) and pig 2 (red). Graphs 3 and 4 represent the increase in subcutaneous fat depth within the 3 measured directions for both pigs: center (red), left (green) and right (yellow). The tables beneath the graphs summarize the measurements and the rates associated with the data.

Image Analysis

CT datasets were imported into the IRW 3.0 image visualization software package, and the subcutaneous adipose tissue on the back at the L3 vertebra was used as a point of reference. Measurements of back fat were made to the left and right of the L3 superior articular processes on the coronal and axial images as well as in a plane extending from the L3 spinous process. Abdominal and pericardial fat depot volumes were estimated by image segmentation in 3D using a volumetric rendering of the CT data.

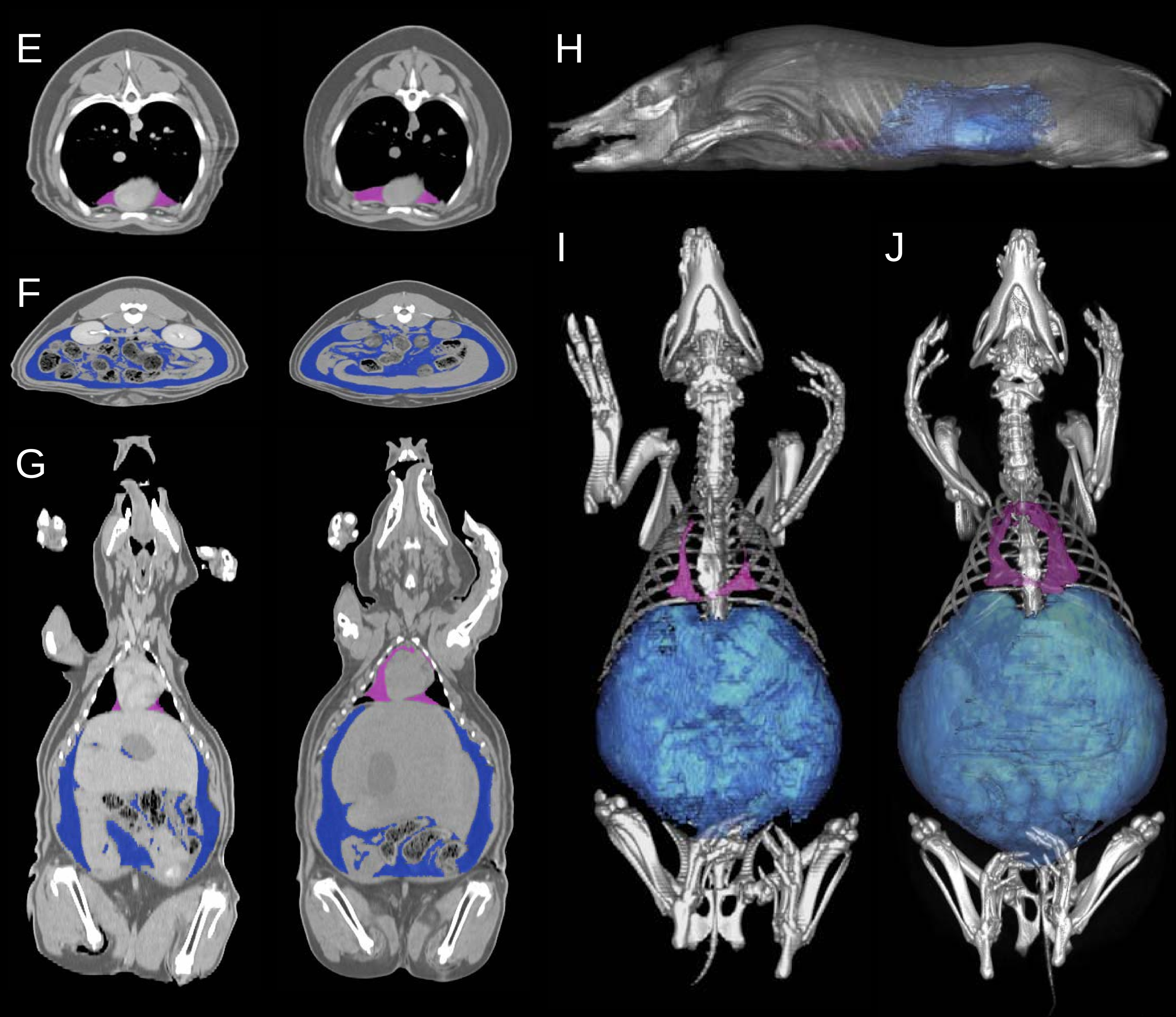


Figure 2: Subcutaneous fat depth was determined by using arrows to demarcate the region of interest. **A** and **C** show the fat depth at 0 months; **B** and **D** show a representative CT at 4 months. The software program provided the length (mm) of the arrow to indicate the fat depth in all designated directions.

Manual segmentation of both pericardial (pink) and abdominal (blue) fat were performed. **E** and **F** show axial orientations of the segmented regions at both the 0 month (left) and 4 month (right) time points. **G** illustrates the segmented regions in roughly the same coronal slice of one pig at both time points.

3D volumetric renderings of both fat depots are illustrated. **H** demonstrates where the 3D regions of interest are positioned within the entire pig volume. **I** and **J** show the fat accumulations at 0 months and 4 months, respectively.

Results and Discussion

Analysis of the data revealed a significant linear correlation between the depth of subcutaneous adipose tissue at the L3 vertebra and both the abdominal and pericardial fat volumes ($p < 0.01$). Similarly, the increase in abdominal fat volume correlated linearly and significantly with pericardial adiposity (Correlation coeff. = 0.96; $p = <0.01$), with a rate of ~ 0.01 - 0.02 cm^3 of pericardial fat/cm^3 of abdominal fat. The rate of accumulation of abdominal adipose tissue was similar in both animals; however, pericardial fat was deposited 2x faster in one pig relative to the other.

Image segmentation of CT data is a facile method for estimating regional adiposity in pigs. Although only two pigs were studied, the data show that regional adiposity can be readily quantified by using CT imaging and that the various methods of image analysis correlated well. This technique will be beneficial for studies of obesity and the quantitative assessment of dietary interventions using the Sinclair minipig or similar models.

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