Does a “Cushion Effect” Really Exist? A Morphomic Analysis of Vulnerable Road Users with Serious Blunt Abdominal Injury

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Research article

Keywords: cushion effect, obesity, subcutaneous fat, vulnerable road user (VRU), abdomen, trauma

Posted Date: March 30th, 2021

DOI: https://doi.org/10.21203/rs.3.rs-354841/v1

Abstract

Background: The severity of injury from motor vehicle crashes (MVCs) depends on complex biomechanical factors, and the body features of the injured person account for some of these factors. By assuming that vulnerable road users (VRU) have limited protection resulting from vehicle and safety equipment, the current study analyzed the characteristics of fat distribution measured by computed tomography (CT) imaging and investigated the existence of a "Cushion effect" in VRU.

Materials and Methods: This retrospective study enrolled 592 VRU involved in MVCs who underwent CT scans. Visceral fat area and subcutaneous fat cross-sectional area were measured and adjusted according to total body area (TBA) and are presented as the visceral fat ratio and the subQ fat ratio (subcutaneous fat ratio). Risk factors for serious abdominal injury [maximum abbreviated injury scale ($MAIS_{abd} \geq 3$)] resulting from MVCs were determined by univariate and multivariate analysis.

Results: $MAIS_{abd} \geq 3$ was observed in 104 (17.6%) of the patients. The SubQ fat ratio at the L4 vertebral level was significantly lower in the $MAIS_{abd} \geq 3$ group than in the $MAIS_{abd} < 3$ group (24.9 ± 12.0 vs 28.1 ± 11.9%; p=0.015). A decreased L4 subQ fat ratio was associated with a higher risk for $MAIS_{abd} \geq 3$ in multivariate analysis (odds ratio 0.063; 95% CI 0.008-0.509; p = 0.009).

Conclusion: The current study supported the "Cushion effect" theory, and protection was apparently provided by subcutaneous fat tissue. This concept may further improve vehicle and safety designation in the future.

Background

Motor vehicle crashes (MVCs) are a leading cause of death in the young population[1]. Injury severity from a crash depends on complex biomechanical factors, such as vehicle type, velocity of crash, type of impact, and safety equipment. Although crash fatality improved after the development and requirement of safety equipment[2], an individual's body features are an unchangeable component in MVCs.

Obesity, characterized as excess fat accumulation, is a growing issue worldwide[3]. It has been widely discussed in the trauma literature. Studies have shown that obesity is associated with a higher risk for posttrauma complications[4] and mortality[5–7]. In contrast, some studies found that obesity protects patients from severe injury[8, 9]. The "Cushion Effect" was introduced by Arbabi et al. in 2003[10] and suggests that increased abdominal adiposity provides a "Cushion" for abdominal trauma during the injury event. However, the establishment of the theory was based on limited data from car occupants[8, 11], and the conclusions remain controversial[12–14].

While body mass index (BMI) is used as a simple indirect assessment of obesity in the trauma population, it does not distinguish between bone, muscle mass, and fat tissue. The development of modern computed tomography (CT) imaging and software enables the precise measurement of body composition. By assessing vulnerable road users (VRU) – the road users with limited abdominal protection during a MVC, we analysed the characteristics of body fat distribution and hypothesized the existence of a “Cushion Effect” in blunt abdominal trauma.

Materials And Methods

Data Collection

The data from May 2008 to December 2016 were collected from the trauma registry of our institution. Individuals who were involved in MVCs were included if they were older than 16 years old, had an abdominal multidetector helical computed tomography (MDCT) scan performed primarily for trauma indications and were admitted to the ward or intensive care unit (ICU). Indications for a MDCT scan included a positive Focus Assessment with Sonography in Trauma (FAST), an abnormal finding in physical examination of the abdomen or pelvis, an abnormal chest or pelvic X-ray, an unconscious occupant with blunt torso injury, or clinical judgement. All occupants underwent MDCT scans if they were hemodynamically stable either with or without resuscitation. Occupants with incomplete medical records or missing body height or weight measurements were excluded.

Data on the following variables were collected: age, sex, height, weight, BMI, Glasgow coma scale (GCS), and vital signs at the emergency department. Vehicle data, including vehicle type and safety equipment, were collected. The VRU are defined as road users that do not have shell protection during a MVC, who consisted of pedestrians, bicyclists and motorcyclists[15]. Injury severity was assessed using the Abbreviated Injury Scale (AIS) and injury severity score (ISS). The AIS ranges from 0 to 6. The maximum abbreviated injury scale (MAIS) of each body region was then determined.

Hemodynamic instability was defined according to at least one episode of systolic pressure less than 90 mmHg upon emergency admission. A MAIS of 3–6 (MAIS ≥ 3) was defined as serious injury in each body region.

Morphomic Variables

CT images were assessed with analytic morphomics, which has been previously described[16, 17]. The total body area (TBA), visceral fat area and subcutaneous fat area were measured from the T9 to L5 vertebrae. The results are given in square centimeters (cm^2) (Fig. 1). Because individuals’ body sizes vary, the visceral fat area and subcutaneous fat area were adjusted according to the TBA at the corresponding vertebral level before further analyses. The results are presented as the visceral and subQ fat ratios (subcutaneous fat ratio, %).

- TBA: The cross-sectional area of the body

- Visceral fat area: The cross-sectional area within the fascia with fat density thresholds between – 205 and – 51 Hounsfield units (HU)
- Subcutaneous fat area: The cross-sectional area between skin and fascia with fat density thresholds between – 205 and – 51 HU

- $\text{Visceral fat ratio (\%)} = \frac{\text{Visceral fat area (cm}^2\text{)}}{\text{TBA (cm}^2\text{)}} \times 100\%$
- $\text{SubQ fat ratio (\%)} = \frac{\text{Subcutaneous fat area (cm}^2\text{)}}{\text{TBA (cm}^2\text{)}} \times 100\%$

Statistical Analysis

Descriptive statistics were calculated for the cohort. Categorical data are presented as numbers and percentages and were compared using the chi-square test. Continuous variables are presented as the mean with standard deviation (SD) or median with interquartile range (GCS, MAIS and ISS). Continuous variables were compared using Student’s t test or the Mann–Whitney U test (for nonnormally distributed data). A multivariable logistic regression model was performed to examine the relationship between serious abdominal injury and the subcutaneous fat ratio, adjusting for patient and crash characteristics.

A significance level of $\alpha = 0.05$ was used. All analyses were performed using IBM SPSS statistics 25.0 (IBM Corporation, Armonk, NY, USA). Microsoft Excel (V16.19) was used for data entry and to create associated figures.

Results

Between May 2008 and December 2016, 592 VRU involved in MVCs underwent abdominal CT scans primarily for trauma evaluation. The demographics of these studied patients are summarized in Table 1. Their mean age and mean BMI were 38.7 ± 18.1 years and 24.2 ± 4.7 kg/m^2, respectively. Of these patients, 59 (10.0%) were pedestrians, and 533 (90.0%) patients were bicyclists or motorcyclists involved in a MVC. A total of 98 patients did not use safety equipment, while the other 494 wore helmets. Upon arrival at our emergency department (ED), 73 individuals (12.3%) had unstable hemodynamics. The median GCS was 15, and the median ISS was 18. Among these individuals, 156 (26.4%) had serious (MAIS ≥ 3) head injuries, 269 (45.4%) had serious thoracic injuries, 104 (17.6%) had serious abdominal injuries, and 175 (29.6%) had serious limb injuries. Overall mortality in the cohort was 5.4%, with a mean length of hospital stay of 16.3 ± 15.7 days and a mean length of ICU stay of 5.1 ± 7.9 days.

Table 1
Characteristics of enrolled VRU.

	N = 592
Demographic Variables	
Age (years) [a]	38.7 ± 18.1
Sex (%)	
M	403 (68.1%)
F	189 (31.9%)
Weight (kg) [a]	67.1 ± 15.2
Height (m^2) [a]	166.1 ± 9.1
BMI (kg/m^2) [a]	24.2 ± 4.7
Vehicle Variables	
Vehicle type (%)	
Pedestrian	59 (10.0%)
Bicyclist/Motorcyclist	533 (90.0%)
Safety equipment type (%)	
No safety equipment	98 (16.6%)
Helmet	494 (83.4%)
Injury Severity	
Unstable haemodynamics (n, %)	73 (12.3%)
Coma scale (GCS) [b]	15 (13–15)
ISS [b]	18 (9–27)
Serious head injury (n, %)	156 (26.4%)
Serious thoracic injury (n, %)	269 (45.4%)
Serious abdominal injury (n, %)	104 (17.6%)
Serious limb injury (n, %)	175 (29.6%)

VRU vulnerable road users, BMI body mass index, GCS Glasgow coma scale, ISS injury severity score, SubQ fat ratio subcutaneous fat ratio, LOS length of hospital stay, ICU LOS length of ICU stay

[a] Mean ± SD [b] Median (25–75% interquartile range)

	N = 592
Morphomics Variables	
L2 visceral fat area (cm^2) [a]	85.33 ± 75.27
L4 subcutaneous fat area (cm^2) [a]	152.30 ± 96.12
L2 visceral fat ratio (%) [a]	14.3% ± 9.9%
L4 subQ fat ratio (%) [a]	27.5% ± 12.0%
Outcomes	
LOS (days) [a]	16.3 ± 15.7
ICU LOS (days) [a]	5.1 ± 7.9
Mortality (%)	32 (5.4%)
VRU vulnerable road users, BMI body mass index, GCS Glasgow coma scale, ISS injury severity score, SubQ fat ratio subcutaneous fat ratio, LOS length of hospital stay, ICU LOS length of ICU stay	
[a] Mean ± SD [b] Median (25–75% interquartile range)	

The fat areas from the T9 to L5 vertebral levels are summarized in Supplementary Table 1. The visceral fat area peaked at the L2 vertebral level, and the subcutaneous fat area peaked at the L4 level (Fig. 2). Hence, the two morphomic variables were used for further analyses in the cohort. After adjusting the fat area according to TBA at the corresponding level, the mean L2 visceral fat ratio was 14.3 ± 9.9%, while the mean L4 subQ fat ratio was 27.5 ± 12.0%.

Table 2 shows a comparison of the characteristics of VRU with and without serious abdominal trauma ($MAIS_{abd} \geq 3$). There were no significant differences in age, BMI, sex, vehicle or safety equipment usage. Occupants with serious abdominal injury did not have a longer length of stay (LOS), and they did not have a higher mortality rate according to the analysis. However, the $MAIS_{abd} \geq 3$ group had a longer ICU LOS (6.5 ± 7.8 vs 4.8 ± 7.9 days, $p = 0.038$). Notably, occupants with a lower mean L4 subQ fat ratio were more likely to have serious abdominal trauma (24.9 ± 12.0 vs 28.1 ± 11.9%, $p = 0.015$), although the BMI was similar.

Table 2
Univariate analysis of risk factors for serious abdominal injury ($MAIS_{abd} \geq 3$) in VRU.

	$MAIS_{abd} < 3$	**$MAIS_{abd} \geq 3$**	***p*-value**
	N = 488 (82.4%)	**N = 104 (17.6%)**	
Demographic Variables			
Age (years) [a]	39.4 ± 18.2	35.7 ± 17.2	0.053
BMI (kg/m^2) [a]	24.3 ± 4.6	24.2 ± 5.4	0.889
Sex (%) [#]			0.781
M	331 (67.8%)	72 (69.2%)	
F	157 (32.2%)	32 (30.8%)	
Participant type [#]			0.076
Pedestrian	53 (10.9%)	6 (5.8%)	
Bicyclist/Motorcyclist	435 (89.1%)	98 (94.2%)	
Safety Equipment (n, %) [#]			0.221
No safety equipment	85 (17.4%)	13 (12.5%)	
Helmet	403 (82.6%)	91 (87.5%)	
Injury Severity			
Coma scale (GCS) [b †]	15 (10–15)	15 (15–15)	0.002*
Unstable haemodynamics (n, %) [#]	56 (11.5%)	17 (16.3%)	0.170

VRU vulnerable road users, BMI body mass index, GCS Glasgow coma scale, ISS injury severity score, MAIS maximal abbreviated injury scale, SubQ fat ratio subcutaneous fat ratio, LOS length of hospital stay, ICU LOS length of ICU stay

[a] Mean ± SD

[b] Median (25–75% interquartile range)

[#] Chi-Squared test

[!] Student's t test

[†] Mann–Whitney U test

* Statistically significant

	$MAIS_{abd} < 3$	$MAIS_{abd} \geq 3$	*p*-value
	N = 488 (82.4%)	N = 104 (17.6%)	
ISS [b †]	17 (9–25)	25 (18–32)	< 0.001*
$MAIS_{head}$ [b †]	0 (0–3)	0 (0–0)	< 0.001*
$MAIS_{chest}$ [b †]	1 (0–3)	3 (0–4)	0.026*
$MAIS_{limb}$ [b †]	2 (0–3)	1 (0–2)	0.001*
Serious head injury (n, %) [#]	149 (30.5%)	7 (6.7%)	< 0.001*
Serious chest injury (n, %) [#]	208 (42.6%)	61 (58.7%)	0.003*
Serious limb injury (n, %) [#]	150 (30.7%)	25 (24%)	0.174
Morphomic Variables			
L2 visceral fat ratio (%) [a !]	14.6 ± 10.0%	13.3 ± 9.0%	0.205
L4 subQ fat ratio (%) [a !]	28.1 ± 11.9%	24.9 ± 12.0%	0.015*
Outcomes			
LOS (days) [a !]	15.9 ± 15.6	18.0 ± 16.3	0.223
ICU LOS (days) [a !]	4.8 ± 7.9	6.5 ± 7.8	0.038*
Mortality (n, %) [#]	29 (5.9%)	3 (2.9%)	0.211

VRU vulnerable road users, BMI body mass index, GCS Glasgow coma scale, ISS injury severity score, MAIS maximal abbreviated injury scale, SubQ fat ratio subcutaneous fat ratio, LOS length of hospital stay, ICU LOS length of ICU stay

[a] Mean ± SD

[b] Median (25–75% interquartile range)

[#] Chi-Squared test

[!] Student’s t test

[†] Mann–Whitney U test

* Statistically significant

Table 3 shows the importance of the variables in the logistic regression model for serious abdominal trauma. When combining the demographic, vehicle and morphomic variables, the results indicated that the risk of serious abdominal trauma increased as the L4 subQ ratio decreased (OR 0.063; 95% CI 0.008–0.509; $p = 0.009$). BMI and L2 visceral fat ratio were not independent predictors of serious abdominal injury. The correlations between the L4 subQ ratio and $MAIS_{abd}$ are shown in Fig. 3. Interestingly, there was a significant trend showing that abdominal injury severity increased as the L4 subQ fat ratio decreased ($\beta = -0.008$, $p = 0.028$).

Table 3
Multivariate logistic regression of risk factors for serious abdominal injury ($MAIS_{abd} \geq 3$).

Variable	**Coef (β)**	**Std Err**	**Odds Ratio**	**95% CI**	***p*-value**
Intercept	-2.135	1.165	0.118		0.067
Age	-0.012	0.009	0.988	0.972–1.005	0.175
BMI	0.035	0.028	1.035	0.979–1.094	0.223
Vehicle type (pedestrian)	0.441	0.470	1.555	0.619–3.906	0.348
L2 visceral fat ratio	0.551	1.677	1.736	0.065–46.464	0.742
L4 subQ fat ratio	-2.758	1.063	0.063	0.008–0.509	0.009*
BMI body mass index, MAIS maximal abbreviated injury scale, SubQ fat ratio subcutaneous fat ratio					
* Statistically significant					

Discussion

The prevalence of obesity is increasing worldwide and has been well studied in terms of the associated cardiovascular and metabolic risks[18–20]. While the literature suggests that the obese trauma population has poorer outcomes than the normal weight trauma population[5, 6, 21], some studies have indicated that increased abdominal adiposity may protect individuals from serious abdominal trauma during frontal MVCs[10].

Adipose tissue can be stored beneath the skin, around organs, and within bone marrow or muscle. In addition to its role in energy storage and endocrine function[22], it also provides protective padding to organs during collision. Although BMI has been widely used as a simple indirect measurement of body mass, it does not distinguish body components. By analysing body composition from CT scans, Wang et al. suggested that increased subcutaneous fat protects females from serious abdominal injury during frontal crashes, but they identified a less significant trend in males[8]. However, the small cohort and fat measurement conducted solely according to fat depth at the L4 vertebral level may not provide conclusive evidence for the “Cushion” phenomenon. In addition, the literature discussing the protective mechanism of fat cushion in trauma patients was limited to car occupants in frontal crashes[10, 12, 13].

Because car occupants are often protected by a metallic chassis, seatbelt or airbag assembly, the current study enrolled VRU who have the least protection from the vehicle and safety equipment. By describing the distribution of torso subcutaneous and visceral fat measured by CT images, the current study found solid evidence that increased subcutaneous fat tissue lowers the risk for serious abdominal injury during MVCs, supporting the concept of the "Cushion" theory in a wider population than previously thought.

The current study demonstrated that the visceral fat area peaks at the L2 vertebral level and that the subcutaneous fat area peaks at the L4 vertebral level. As fat area varies with body size, it was adjusted according to the TBA for further analysis. Interestingly, subcutaneous fat was found to be a stronger protective factor against serious abdominal trauma during MVCs than visceral fat, showing that subcutaneous fat tissue is more likely to disperse forces during crashes.

Viano et al. found that obese patients had a 40% higher risk of serious injury than normal weight patients. However, the abbreviated injury scales of each body region were not discussed[14]. In the current study, occupants with serious abdominal trauma had a 10–20% lower L4 subQ fat ratio than the minor abdominal injury group, and the difference was significant. Surprisingly, low BMI was not an independent risk factor for serious abdominal trauma. Despite the fact that momentum increases as mass increases, the results revealed that abdominal injury severity might differ due to different quantities and distributions of subcutaneous fat under conditions of similar momentum.

The current cohort was from a level I trauma center in Taiwan, with a median ISS of 17.5 and an overall in-hospital mortality rate of 5%, which was in line with a previous report[5, 7, 23, 24]. Although an increased L4 subQ ratio protected occupants from serious abdominal trauma, it was not associated with mortality reduction, which could be explained by the low correlation between abdominal injury severity and mortality [25]. However, occupants with serious abdominal trauma had a significantly longer ICU LOS.

Finally, it is important to realize that the current study was limited due to its retrospective nature. A lower rate of obesity and morbid obesity in Asia also limited the ability to demonstrate a full picture of the "Cushion Effect". Furthermore, vital organs such as the liver, spleen, and kidneys are located between the T11 and L2 vertebral levels. An analysis of fat area at a single vertebral level may not be conclusive.

Conclusion

The advancement of CT imaging provides a chance to inspect the complex interaction between the human body and injury. The results of the current study supported the existence of a fat cushion effect. Increased abdominal fat in VRU involved in MVCs is associated with a lower prevalence of serious abdominal trauma. The concept may further improve the development of vehicles and safety features in the future.

Abbreviations

MVCs Motor vehicle crashes

VRU Vulnerable road users

BMI Body mass index

CT Computed tomography

MDCT Multidetector helical computed tomography

ICU Intensive care unit

FAST Focus Assessment with Sonography in Trauma

GCS Glasgow Coma Scale

AIS Abbreviated Injury Scale

MAIS Maximum Abbreviated Injury Scale

ISS Injury Severity Score

TBA Total body area

SubQ fat ratio Subcutaneous fat area

SD Standard deviation

ED Emergency department

Declarations

Conflict of interest statement: Dr. Stewart C. Wang discloses a financial relationship with Prenovo and Morphomic Analysis Group, LLC. For the remaining co-authors, no conflicts are declared.

Ethics approval and consent to participate:

This study was approved by the ethics committee of Chang Gung Memorial Hospital (IRB No. 201601352B0C501), and the requirement to obtain informed consent was waived.

Consent for publication:

Not applicable.

Availability of data and materials"

This study was based on datasets from the trauma registry databank of Chang Gung Memorial Hospital. The datasets used and analysed are only available for review when approved by the Ethics Institutional Review Board of Chang Gung Memorial Hospital.

Competing interest:

Dr. Stewart C. Wang discloses a financial relationship with Prenovo and Morphomic Analysis Group, LLC. For the remaining coauthors, no conflicts are declared.

Funding

Current study did not receive any sources of funding for research and publication.

Author Contribution

Y-ST, C-YF, S-CK, and C-HH contributed to the design of the research. Y-ST, C-TC, and C-YF contributed to the analysis and interpretation of the data. BAD, GLS, and SCW contributed to the acquisition and interpretation of the data. All authors critically revised, read and approved the final manuscript.

Acknowledgement

This study was supported by Linkou Chang Gung Memorial Hospital (grants CORPG3F0511, CORPG3F0521, CORPG3F0531, and CORPG3F0541).

References

1. Heron M. Deaths: Leading Causes for 2017. *Natl Vital Stat Rep* Jun. 2019;68(6):1–77.
2. Crandall CS, Olson LM, Sklar DP. Mortality reduction with air bag and seat belt use in head-on passenger car collisions. *Am J Epidemiol* Feb. 2001;1(3):219–24. doi:10.1093/aje/153.3.219. 153) .
3. Health Effects of. Overweight and Obesity in 195 Countries over 25 Years. N Engl J Med. 2017;377(1):13–27. doi:10.1056/NEJMoa1614362.
4. He K, Brown E, Derstine B, et al. Using Morphomic Analysis of Soft-Tissue Injury to Predict Trauma Outcomes. J Am Coll Surg. 2018;10/01:227:S277. doi:10.1016/j.jamcollsurg.2018.07.571.
5. Ditillo M, Pandit V, Rhee P, et al. Morbid obesity predisposes trauma patients to worse outcomes: a National Trauma Data Bank analysis. *The journal of trauma acute care surgery* Jan. 2014;76(1):176–9. doi:10.1097/TA.0b013e3182ab0d7c.
6. Glance LG, Li Y, Osler TM, Mukamel DB, Dick AW. Impact of Obesity on Mortality and Complications in Trauma Patients. Annals of surgery. 2014;259(3):576–81. doi:10.1097/sla.0000000000000330.
7. Neville AL, Brown CV, Weng J, Demetriades D, Velmahos GC. Obesity is an independent risk factor of mortality in severely injured blunt trauma patients. *Arch Surg* Sep. 2004;139(9):983–7. doi:10.1001/archsurg.139.9.983.
8. Wang SC, Bednarski B, Patel S, et al. Increased depth of subcutaneous fat is protective against abdominal injuries in motor vehicle collisions. Annu Proc Assoc Adv Automot Med. 2003;47:545–59.
9. Fu CY, Bajani F, Butler C, et al. Morbid Obesity's Silver Lining: An Armor for Hollow Viscus in Blunt Abdominal Trauma. *World journal of surgery* Apr. 2019;43(4):1007–13. doi:10.1007/s00268-018-

4872-7.

10. Arbabi S, Wahl WL, Hemmila MR, Kohoyda-Inglis C, Taheri PA, Wang SC. The cushion effect. *J Trauma*. 2003/06// 2003;54(6):1090–1093. doi:10.1097/01.ta.0000064449.11809.48.
11. Boulanger BR, Milzman D, Mitchell K, Rodriguez A. Body habitus as a predictor of injury pattern after blunt trauma. *J Trauma* Aug. 1992;33(2):228–32. doi:10.1097/00005373-199208000-00011.
12. Harbaugh CM, Zhang P, Henderson B, et al. Evaluating the "cushion effect" among children in frontal motor vehicle crashes. *J Pediatr Surg* May. 2018;53(5):1033–6. doi:10.1016/j.jpedsurg.2018.02.042.
13. Harbaugh CM, Henderson B, Zhang P, et al. The@ Cushion Effect' Is Not Protective for Children Involved in Motor Vehicle Crashes. *Journal of the American College of Surgeons*. 2017;225.
14. Viano DC, Parenteau CS, Edwards ML. Crash injury risks for obese occupants using a matched-pair analysis. *Traffic Inj Prev* Mar. 2008;9(1):59–64. doi:10.1080/15389580701737645.
15. Wegman FC, Aarts L. Advancing sustainable safety: National Road Safety Outlook for 2005–2020. 2006.
16. Zhang P, Peterson M, Su GL, Wang SC. Visceral adiposity is negatively associated with bone density and muscle attenuation. *Am J Clin Nutr* Feb. 2015;101(2):337–43. doi:10.3945/ajcn.113.081778.
17. Chughtai K, Song Y, Zhang P, et al. Analytic morphomics: a novel CT imaging approach to quantify adipose tissue and muscle composition in allogeneic hematopoietic cell transplantation. *Bone Marrow Transplantation*. 2016/03/01 2016;51(3):446–450. doi:10.1038/bmt.2015.267.
18. *The Lancet*. 2009;373(9669):1083–1096. doi:10.1016/S0140-6736(09)60318-4.
19. Nguyen NT, Magno CP, Lane KT, Hinojosa MW, Lane JS. Association of hypertension, diabetes, dyslipidemia, and metabolic syndrome with obesity: findings from the National Health and Nutrition Examination Survey, 1999 to 2004. *Journal of the American College of Surgeons* Dec. 2008;207(6):928–34. doi:10.1016/j.jamcollsurg.2008.08.022.
20. Aune D, Sen A, Norat T, et al. Body Mass Index, Abdominal Fatness, and Heart Failure Incidence and Mortality: A Systematic Review and Dose-Response Meta-Analysis of Prospective Studies. *Circulation* Feb. 2016;16(7):639–49. doi:10.1161/circulationaha.115.016801. 133) .
21. Ryb GE, Dischinger PC. Injury severity and outcome of overweight and obese patients after vehicular trauma: a crash injury research and engineering network (CIREN) study. *J Trauma* Feb. 2008;64(2):406–11. doi:10.1097/TA.0b013e31802beff9.
22. Scheja L, Heeren J. The endocrine function of adipose tissues in health and cardiometabolic disease. *Nature Reviews Endocrinology*. 2019/09/01 2019;15(9):507–524. doi:10.1038/s41574-019-0230-6.
23. Bardes JM, Inaba K, Schellenberg M, et al. The contemporary timing of trauma deaths. *The journal of trauma acute care surgery* Jun. 2018;84(6):893–9. doi:10.1097/ta.0000000000001882.
24. Neal MD, Peitzman AB, Forsythe RM, et al. Over reliance on computed tomography imaging in patients with severe abdominal injury: is the delay worth the risk? *J Trauma* Feb. 2011;70(2):278–84. doi:10.1097/TA.0b013e31820930f9.

25. Rau CS, Wu SC, Kuo PJ, et al. Same Abbreviated Injury Scale Values May Be Associated with Different Risks to Mortality in Trauma Patients: A Cross-Sectional Retrospective Study Based on the Trauma Registry System in a Level I Trauma Center. *Int J Environ Res Public Health* Dec 11 2017;14(12)doi:10.3390/ijerph14121552.

Figures

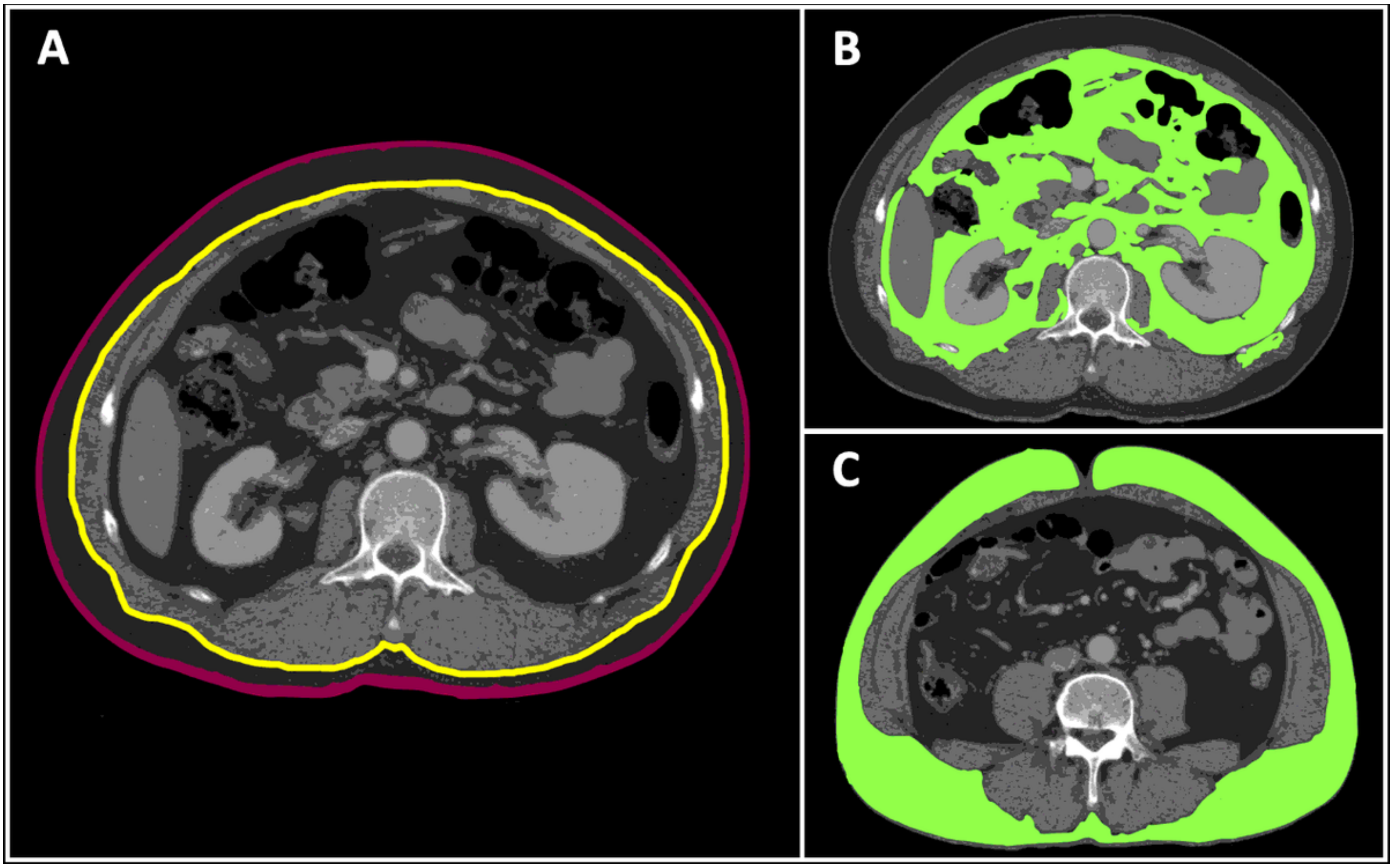

Figure 1

This figure demonstrates the morphomic variable measurements of a 53-year-old male motorcyclist by a CT scan. Total body area was measured by the cross-sectional area inside the purple line (A), whereas visceral fat area (at the L2 vertebral level) was represented by the area inside the fascia (yellow line) meeting fat density thresholds (B), and subcutaneous fat area (at the L4 vertebral level) was represented by the area between the skin and fascia meeting fat density thresholds (C).

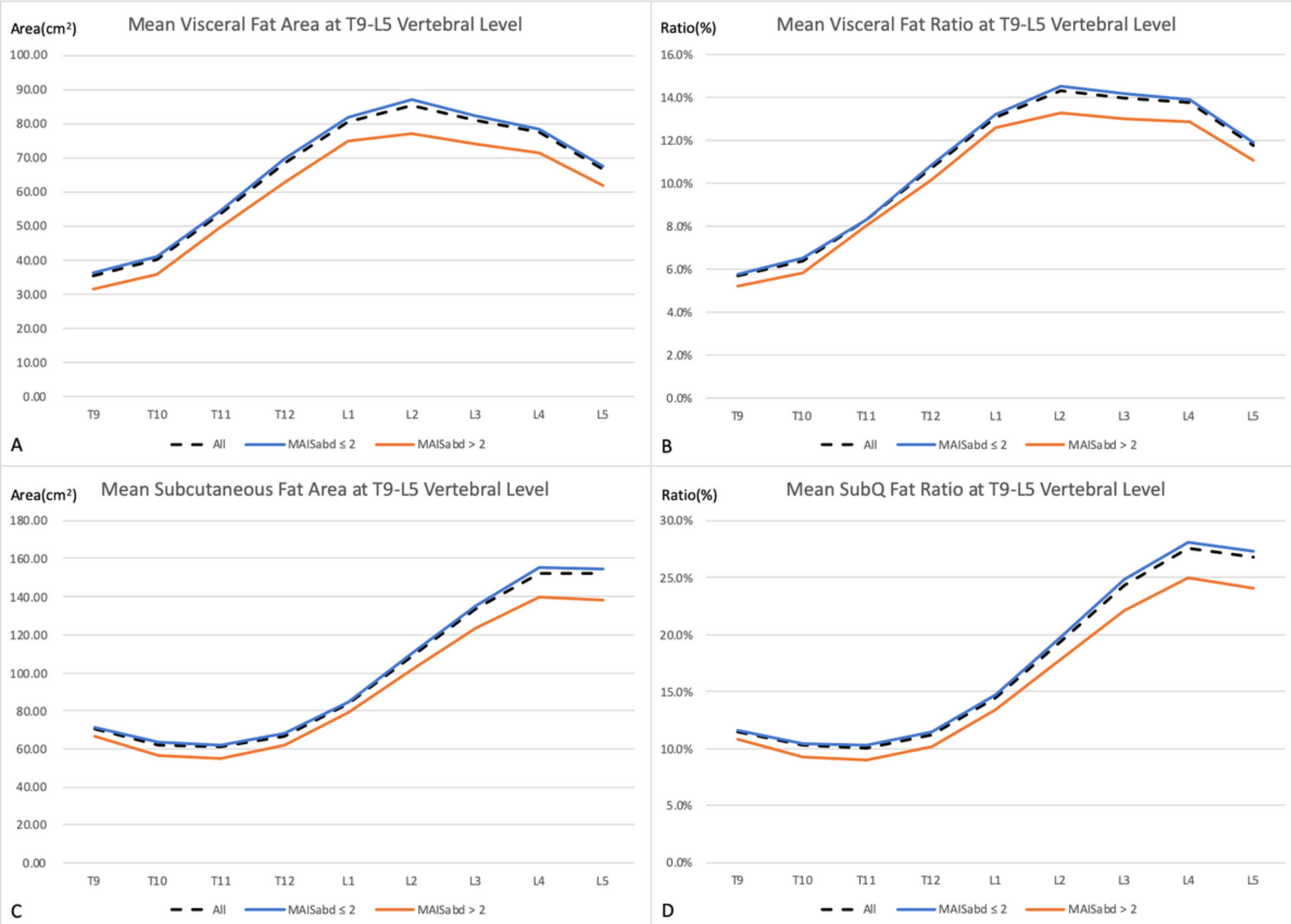

Figure 2

A-D. Mean visceral fat area (A) and subcutaneous fat area (C) from the T9-L5 vertebral level are shown. The visceral fat ratio (B) and subQ fat ratio (D) were obtained. While visceral fat area and ratio peaked at the L2 level, subcutaneous fat area and ratio peaked at the L4 level. Vulnerable road users (VRU) with serious abdominal injury (MAISabd ≥ 2) had lower fat areas and ratios than those with minor injury.

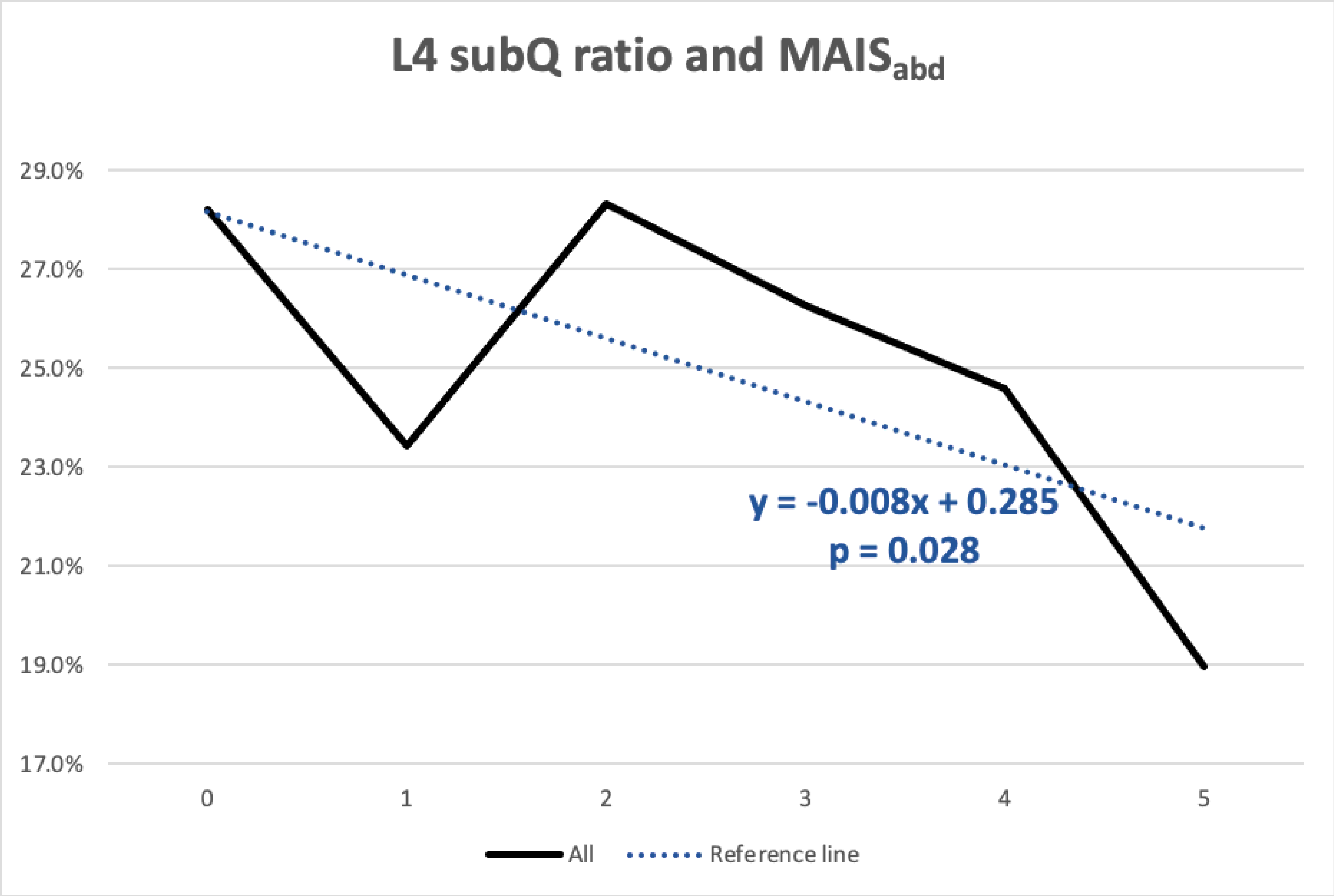

Figure 3

This figure shows that the mean L4 SubQ fat ratio is inversely correlated with abdominal MAIS (p = 0.028).

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Supplementarytable2021.03.22.docx