Effect of hand positioning on iDXA precision error for total and regional bone and body composition parameters.

Abstract

Dual energy X-ray absorptiometry (DXA) body composition measurements are performed in both clinical and research settings for estimations of total and regional fat mass (FM), lean tissue mass (LM) and bone mineral content (BMC). Subject positioning influences precision and positioning instructions vary between manufacturers. The aim of the study was to determine the effect of hand position and scan mode on regional and total body bone and body composition parameters and determine protocol-specific body composition precision errors. Methods: Thirty eight healthy subjects (men; mean age: 27.1 ± 12.1 years) received four consecutive total body (TB) Lunar iDXA (enCORE v 15.0) scans with re-positioning, and scan mode was dependent on body size. Twenty three subjects received scans in standard mode and fifteen received scans in thick scan modes. Two scans per subject were conducted with subject hands prone and two with hands mid-prone. The precision error (RMS-SD; %CV) and least significant change (LSC) for each protocol were determined using the International Society for Clinical Densitometry calculator. Results: Hands placed in the mid-prone position increased arm BMD (standard mode: 0.185 g*cm-2, thick mode: 0.265 g*cm-2; $p < 0.05$), total body BMD (standard mode: 0.051 g*cm-2, thick mode: 0.069 g*cm-2; $p < 0.001$) and total body BMD Z-score (standard mode: 0.5. thick mode: 0.7; $p < 0.001$). This was due to reductions in bone area and BMC. In standard mode, hands mid-prone reduced fat mass (0.05 kg, $p < 0.05$) and increased lean mass (0.11 kg, $p < 0.05$). There were no differences in body composition for thick mode scans. Hands mid-prone reduced lean mass precision error at the arms, trunk and total body ($p < 0.01$). Conclusions: DXA clinical and research centres are advised to maintain consistency in their hand positioning and scan mode protocols, and consideration should be given to the hand positioning used for reference data. As a best practice recommendation, published DXA-based studies and reports for clinic-based total body assessments should ensure that subject positioning is fully described.

Key words: *DXA; precision error; measurement protocol; fat mass; lean mass; bone mineral content.*

Introduction

Dual energy X-ray absorptiometry (DXA) is a non-invasive, rapid method of measuring three components of body composition: fat mass (FM), lean mass (LM) and bone mineral content (BMC), providing precise quantification at the total body and regional (left and right arms, legs and trunk) level. Over the last decade, there has been a rise in the use of DXA for the assessment of body composition in obesity (1), ageing (2) and in athletes (3-5), most likely reflecting increased availability, quicker scan acquisition times and improved resolution and image quality with fan beam densitometers. The low effective radiation dose of total body DXA, which is typically around 2-6 µSv depending on scan mode, means that the technology is also suitable for longitudinal monitoring of body composition. Longitudinal DXA body composition studies have included investigations of the effect of exercise training (6, 7), of athletic competition (8, 9, 10) and dietary interventions (11, 12).

As with bone density longitudinal studies, those assessing body composition should also first establish precision error from repeat scans with re-positioning, in a group which reflects the study population (13, 14). A significant change (LSC) occurs if the value exceeds the 95% confidence interval of the precision error defined as the root mean squared standard deviation (RMS-SD) of the repeat measurements (13, 14). Consistency of subject positioning influences precision error and the International Society for Clinical Densitometry (ISCD) recommend that positioning for total body scans follow the instructions of the National Health and Nutrition Examination Survey (NHANES) 2011 protocol with hands placed in the prone position isolated from the hip, and with legs supported together by a Velcro strap (15). However, with the greater body size of obese subjects and athletes from certain sports, there is a problem of accurately positioning these subjects within the lateral boundaries of the scanning table. As such, the recent software release from GE Lunar (Encore version 15.0) recommends that hands should now be placed in the mid-prone position with a space of >1 cm between the hands and hip. This position reduces the scan width of the subject enabling the subject to fit within the scan boundaries and is supported by the detailed methodological work of Nana and colleagues (16).

To our knowledge, only one study to date has investigated the effects of the two hand positioning protocols on DXA outcomes, using a pencil beam GE-Lunar DPX densitometer (17). It is important to ascertain any differences for all models of DXA and so that recommendations can be made for best practice. Accordingly, the aim of the current study was to determine the effect with hands prone and mid-prone on GE-Lunar iDXA total and regional bone and body composition parameters, scan mode and precision error.

Materials and Methods

Study group and study design

The study group consisted of 38 physically active male adults with a mean age of 27.1 ± 12.1 years who participated in at least 3 hours of physical activity per week (>12 months). Approval for the study was provided by the University Faculty Research Ethics Committee and informed signed consent was attained before scans, from all volunteers. All activities performed in this study were in accordance with The Declaration of Helsinki.

Prior to all scans, each participant was asked to refrain from exercise in the preceding 12 hours, to fast overnight and drink an additional 500 ml water in the evening before and morning prior to testing. On arrival, participants were asked to void their bladder. For all measurements, participants wore light clothing (underwear or shorts and t-shirt) with all metal and plastic artefacts removed. Height was measured on a stadiometer and recorded to the nearest millimeter and body mass was measured on calibrated electronic scales to the nearest gram (both SECA, Birmingham, UK). The group ranged widely in body mass (63.6 - 125.0 kg) and height (161.0 - 191.0 cm). Four consecutive total body GE Lunar iDXA (GE Healthcare, Madison, WI) scans were conducted on each participant, with full dismounting of the bed and re-positioning between scans. Two of the scans were conducted in accordance with the ISCD recommended NHANES hands prone protocol and two were conducted using the Lunar iDXA recommended hands mid-prone protocol. Initial hand position was randomly assigned. The feet were separated by 15 cm for all scans. Standard or thick scan mode was machine-selected and dependent on body size.

DXA scan mode and positioning protocols

The manufacturer's guidelines state that the standard mode is used for an estimated body thickness between 16 and 25 cm, and the thick scan mode, for an estimated body thickness greater than 25 cm. Scans conducted in the thick mode have an increased acquisition time from ~7 to ~14 min and an increased dose rate from 3.0 μGy to 6.0 μGy compared to the standard scan mode. In the current study, 23 subjects were scanned in standard mode and 15 in thick mode, over a period of 8 weeks.

Participants were positioned centrally on the scanning bed (65 cm wide and 196 cm in length) within the transverse scan width of the densitometer with feet separated by 15 cm and supported with a Velcro strap. On the scanning bed, the maximum separation between arm and trunk was set and the palm of the hand was placed on the bed (hand prone). All scan images in this study were within the scan field of the densitometer and accurate adjustment of the regions of interest could be made. For the hand in the mid-prone position, there was at least a 5cm space between the palm and thigh, the thumb was placed in line with the first finger and the arms were easily placed within the scan region.

Scan analysis

The scans were analysed using encore software version 15.0 for the iDXA, and adjustment of the cuts which define regional analysis made. The arms and trunk were separated by lines through the glenohumeral joints and the trunk and legs by lines obliquely through the hip joint at 45^{o} to the sagittal plane of the body image. The head was excluded from the trunk region by a transverse line below the mandible. The trunk includes the thorax, abdomen, pelvis and a portion of the medial thigh. The android region of interest (ROI) is at the lower boundary of the pelvis cut and the upper boundary above the pelvis cut 20% of the distance between pelvis and neck cuts. Lateral boundaries are the arm cuts. The gynoid ROI upper boundary is below the pelvis cut by 1.5 times the height of the android ROI, and the gynoid ROI height is equal to two times the height of the android ROI. The lateral boundaries are the outer leg cuts. For consistency, manual ROI analysis of each scan was performed by the same experienced and ISCD certified clinical densitometrist.

Quality assurance (QA) tests were performed using the GE calibration block which has a tissue chamber for %fat with three compositions, high, normal and low. Over the study period the calibration values were %fat (high) = 60.60 ± 0.01; %fat (normal) = 36.55 ± 0.07, %fat (low) = 7.55 ± 0.07, indicating no drifts in soft tissue calibration throughout the study period.

Statistical analysis

Statistical analysis was performed using Microsoft Excel 2016 and IBM SPSS Statistics (V24). The data were assessed for normality using the Shapiro-Wilks test and were presented as mean ± standard deviation. For normal distributed data two-tailed paired *t*-test were used and for non-normal distributed data Wilcoxon signed rank test was used to determine differences in bone and body composition parameters due to the hand positioning protocol. Precision error for total body and regional body composition parameters used the root mean square standard deviation (RMS-SD) and percentage coefficient of variation (%CV) error for each protocol and scan mode and was calculated using the ISCD advanced precision calculator (http://www.iscd.org/resources/calculators). The F-test and Levene's test of equality of variance were used to compare the RMS-SD precision errors between prone and mid-prone hand position and standard/thick scan modes. The least significant change (LSC) at the 95% confidence interval was calculated using the calculation $2\sqrt{2}$* Precision. Statistical significance was defined as $p \leq 0.05$.

Results

The physical characteristics of the two study groups are given in Table 1. Figure 1 indicates the differences in the scan position of the hands. In the mid-prone position both the hand and forearm have reduced bone area. Regions of interest were placed at the hand and forearm of a single subject to determine bone and body composition differences between the two hand positions (Table 2). With the hand in the mid-prone position, bone analysis indicated reduced bone area at both the hand and forearm (the radius and ulna observed as a single bone) with no change in BMC, hence BMD of the hand and forearm regions were increased. Body composition analysis of the hand region in the mid-prone position indicated an increase in FM with LM unchanged. No differences were observed in the forearm FM or LM between the two hand positions.

To study the effects of hand positioning on the regional and total body bone parameters, Prone $_1$ and Mid-prone $_1$ measurements were compared for both scan modes (Table 3). In the standard mode with the hand in mid–prone position, there was a small significant decrease in arm BMC (5 g, $p < 0.05$) and a significant decrease in arm bone area (81 cm^2 $p < 0.05$). This results in a significant increase in arm BMD (*0.185* g*cm^{-2}; $p < 0.05$). These results were reflected in the total body bone analysis, with a significant decrease in BMC (14 g, $p < 0.05$) and a significant decrease in area (202 cm^2, $p < 0.01$) resulting in a significant increase in BMD (0.051g*cm^{-2}; $p < 0.001$) and Z-score 0.5 ($p < 0.001$). Small significant decreases were observed with the hand in the mid-prone position in the trunk region for BMC (6 g, $p < 0.05$) and area (6 cm^2, $p < 0.01$).

Similar results were observed for the thick scan mode. With the hand in the mid-prone position a highly significant decrease in arm bone area (119 cm^2; $p < 0.001$) resulted in a highly significant increase in arm BMD (0.265 $g*cm^{-2}$; $p < 0.001$). For total body there was a small significant increases in BMC (13 g, $p < 0.05$) and a significant decrease in area (131 cm^2, $p < 0.001$) and a highly significant increase in BMD (0.069 $g*cm^{-2}$; $p<0.001$) and Z-score 0.7 ($p < 0.001$). Small significant decreases were observed in the leg BMC (5 g; $p < 0.05$) and trunk area (8 cm^2; $p < 0.05$).

The effect of hand positioning on total and regional body composition parameters for the two scan modes are given in Table 4. The only significant differences were observed in the arm region with the standard scan mode. With the hand in the mid-prone position, a significantly lower fat mass (0.05 kg; $p<0.05$) and BMC (5 g; $p < 0.05$) with an increased lean mass (0.11 kg; $p < 0.05$) were observed compared to the hand prone position. No significant differences between body composition parameters with hand position were observed for the thick scan mode.

The effect of hand positioning on precision error (RMS-SD) for the standard and thick scan modes for total and region body composition measurements are given in Table 5. For the standard mode with the hand in the mid-prone position a significant reduction in lean mass precision error was observed for the arm region (0.08 kg to 0.13kg; $p < 0.01$) with significant improvements in lean mass precision errors at the trunk (0.36 kg to 0.26kg; $p < 0.01$) and total body (0.25kg to 0.20kg; $p < 0.05$). Hand positioning had no significant effect on fat mass or BMC precision error. Thick scan mode and hands in the mid-prone position showed significantly improved precision error for lean mass at the legs (0.33 kg to 0.26 kg, $p < 0.05$) and trunk (0.40 kg to 0.32 kg; $p < 0.01$) compared to hands in the prone position. Fat mass and BMC precision errors were comparable between hand positions.

The thick scan mode had significantly higher precision error values compared to the standard mode for most body composition parameters ($p < 0.05 – 0.001$) with but with comparable %CV. Therefore there will be different LSC values for body composition parameters between standard and thick scan mode

Care should be taken when stating precision, with hands mid-prone the standard scan mode trunk lean mass precision = 0.26 kg and the thick scan mode precision = 0.32 kg and were significantly different ($p < 0.001$) but both had identical %CV = 0.9%. Therefore, precision should be stated as RMS-SD (%CV).

Discussion

This study was performed to determine if differences exist in body composition parameters, precision error and LSC between DXA total body measurements conducted with the hands placed prone (NHANES) and the hands placed mid-prone. Our main finding was that total body and arm BMD are not comparable between the two hand positioning protocols. With the hand in the mid-prone position the radius and ulna are observed as a single bone. This results in a small significant reduction in arm and total body BMC and highly significant reduction of arm and total body bone area, resulting in an increase of BMD at the arm and total body with the hand in the mid-prone position. This also resulted in an increase in total body BMD Z-score. Technologists must be aware that the BMD reference data will have been derived with the hands prone and advised to ensure consistency in total body DXA longitudinal measurement patient positioning.

The only difference observed in body composition parameters between the two hand positions was at the arm, where we found a small significant reduction in fat mass and a small significant increase in lean mass with the hands in the mid-prone position. The absence of differences in bone and body composition parameters at the leg and trunk regions plausibly reflects that only the hand and forearm positioning differed between the two protocols.

Although precision error for total body composition was similar for both hand positioning protocols, there were differences in precision error for lean mass measurements. With the hands in the mid-prone position the arm lean mass had an increased precision error while the legs, trunk and total body lean mass had reduced precision errors. Comparison of precision errors of the body composition parameters between the two scan modes indicated increases in precision errors for most parameters with the thick scan mode. Elsewhere, there has only been one other previous study comparing the effects of prone and mid-prone hand positioning on total and regional body composition outcomes (17). The study was performed on a pencil beam GE-Lunar DPX densitometer using positioners at the hands and feet, and it was concluded that scanning subjects with the hands in the mid-prone position improves precision error for regional (arms and trunk) fat mass and BMC. However, the authors also report that the two protocols give substantially different body composition assessments.

There are advantages and disadvantages associated with both hand positioning protocols. Hands mid-prone provides a more feasible position when performing scans in obese or athletic subjects who are broad at the shoulders because in this position, it is easier to place subjects within the scan boundaries and facilitates precision in cuts for regional analysis. This would also reduce the need for conducting half-body scans in such scenarios. Attention should be given to the positioning protocols used for reference data. The major reference databases for total body densitometry, such as NHANES, were acquired using the hands prone position and therefore is not compatible for comparison of scans that are acquired using the hands mid-prone position.

The precision error findings for total body lean and fat mass derived using both hand positioning protocols are within ISCD recommended ranges (12) and are similar to those reported by other studies in men athletes (LM 0.21 kg, 0.3%; FM 0.17 kg, 1.5 %) (18), senior rugby league players (LM 0.36 kg, 2.4%; FM 0.33 kg, 2.9 %) (19) and normal (LM 0.22 kg, 0.5%; FM 0.18 kg, 1.0%, LM 0.24 kg, 0.5%; FM 0.20 kg, 0.8%) (20, 21). Precision error should be reported for both RMS SD and %CV though, highlighted by Carver and co-workers whose study in obese subjects reported similar %CV values (LM 1.0% and FM 0.9%), with reported RMS SD values at a factor of three higher than the studies cited above (22).

Our findings should be interpreted with consideration that the two groups of subjects (n = 23 and n = 15) are less than the ISCD recommended study group size (14). Further research work is needed to determine if the effect of positioners at the hands and feet would reduce the precision error.

Conclusions

Total body DXA scans are not comparable for total BMD, regional arm fat mass and the associated precision error when interchanging hand positioning from hands prone to hands mid-prone. We clarify the importance of consistency in hand positioning for longitudinal monitoring and for standardised practice within a centre. As best practice, published DXA-based studies and reports for clinic-based total body assessments should ensure that subject positioning is fully described. It is also recommended that attention is given to the hand positioning used for reference data.

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Table 1 Physical characteristics of the two study groups.

Group	Age (y) (range)	Height (cm) (range)	Weight (kg) (range)	iDXAwt (kg) (range)	BMI ($kg*m^{-2}$) (range)
Scan Mode					
Standard (n=23)	24.5 ± 9.4 (18.0 – 59.9)	179.3 ± 4.7 (171.4 – 188.5)	86.5 ± 7.8 (63.6 – 125.0)	86.6 ± 7.7 (64.0 – 101.4)	26.9 ± 2.1 (20.1 – 30.5)
Thick (n=15)	29.5 ± 13.7 (18.7 – 61.1)	183.3 ± 5.3 (169.3 – 191.0)	110.3 ± 8.1 (98.0 – 125.0)	110.2 ± 7.8 (97.9 – 124.0)	32.8 ± 2.7 (29.2 – 37.9)

Mean ± sd

Table 2. Differences in iDXA bone and body composition parameters of the hand and forearm according to hand position, derived from a single subject's total body scan.

	Hand			Forearm		
Hand position	BMC (g)	Area (cm^2)	BMD ($g*cm^{-2}$)	BMC (g)	Area (cm^2)	BMD ($g*cm^{-2}$)
Prone	53	101	0.519	100	95	1.049
Mid-prone	55	47	1.155	100	65	1.547
	%Fat	Fat mass (g)	Lean mass (g)	%Fat	Fat mass (g)	Lean mass (g)
Prone	17.8	129	594	7.9	154	1796
Mid-prone	24.3	196	609	7.7	153	1827

Table 3 Mean, standard deviation and differences of regional and total body bone parameters with the hand in the prone and mid-prone positions for the two scan modes

	STANDARD (n=23)				THICK (n=15)			
	BMC (g)	Area (cm^2)	BMD ($g*cm^{-2}$)	Z-score	BMC (g)	Area (cm^2)	BMD ($g*cm^{-2}$)	Z-score
ARMS								
Prone	518 ± 83	524 ± 80	0.979 ± 0.168		601 ± 89	581± 51	1.030 ± 0.083	
Mid-prone	513 ± 84	443 ± 56	1.164 ± 0.164		600 ± 88	462 ± 33	1.295 ± 0.132	
Difference	5 ± 13*	81 ± 116*	0.185 ± 0.207*		1 ± 15	119 ± 30***	0.265 ± 0.066***	
LEGS								
Prone	1444 ± 218	897 ± 60	1.605 ± 0.180		1616 ± 185	967 ± 76	1.668 ± 0.108	
Mid-prone	1446 ± 217	898 ± 60	1.606 ± 0.180		1611 ± 183	963 ± 69	1.669 ± 0.112	
Difference	2 ± 11	1 ± 15	0.001 ± 0.024		5 ± 13*	4 ± 14	0.001 ± 0.021	
TRUNK								
Prone	1263 ± 220	944 ± 74	1.337 ± 0.168		1458 ± 234	1041 ± 88	1.395 ± 0.135	
Mid-prone	1257 ± 216	938 ± 75	1.332 ± 0.164		1453 ± 231	1033 ± 83	1.399 ± 0.138	
Difference	6 ± 20*	6 ± 14**	0.005 ± 0.043		5 ± 30	8 ± 19*	0.004 ± 0.015	
TOTAL BODY								
Prone	3824 ± 523	2627 ± 168	1.454 ± 0.149	2.1 ± 1.4	4307 ± 510	2830 ± 185	1.518 ± 0.110	2.3 ± 1.1
Mid-prone	3810 ± 524	2525 ± 141	1.505 ± 0.153	2.4 ± 1.4	4294 ± 505	2699 ± 158	1.587 ± 0.117	3.0 ± 1.2
Difference	14 ± 42*	102 ± 114**	0.051 ± 0.054**	0.3 ± 0.5**	13 ± 27*	131 ± 42***	0.069 ± 0.020***	0.7 ± 0.2***

Mean ± sd * $p < 0.05$ ** $p < 0.01$ ***$p < 0.001$ significantly different from zero.

Table 4 Mean, standard deviation and ranges of regional and total body composition parameters with the hand in the prone and mid-prone positions for the two scan modes.

	Standard (n=23)			Thick (n=15)		
	FAT MASS (kg)	LEAN MASS (kg)	BMC (g)	FAT MASS (kg)	LEAN MASS (kg)	BMC (g)
ARMS						
Prone (1,2)	1.50 ± 0.45	8.39 ± 1.17	518 ± 83	2.55 ± 0.84	10.42 ± 1.70	601 ± 89
Mid-prone (1,2)	1.45 ± 0.43*	8.50 ± 1.22*	513 ± 84*	2.55 ± 0.87	10.47 ± 1.77	600 ± 88
Range	(0.62 – 2.77)	(5.45 – 10.87)	(339 – 746)	(1.12 – 4.71)	(7.56 – 13.87)	(437 – 785)
LEGS						
Prone (1,2)	5.23 ± 1.53	24.25 ± 2.67	1444 ± 218	8.45 ± 2.63	29.15 ± 3.39	1616 ± 185
Mid-prone (1,2)	5.25 ± 1.56	24.33 ± 2.67	1446 ± 217	8.47 ± 2.59	29.07 ± 3.41	1611 ± 183
Range	(1.78 – 9.26)	(18.43 – 29.51)	(1036 – 1917)	(3.84 – 12.46)	(21.88 – 32.88)	(1275 – 1897)
TRUNK						
Prone (1,2)	7.38 ± 3.59	31.55 ± 2.98	1263 ± 220	14.89 ± 6.61	35.66 ± 3.95	1458 ± 234
Mid-prone (1,2)	7.38 ± 3.62	31.37 ± 3.00	1257 ± 216	14.94 ± 6.57	35.69 ± 3.87	1453 ± 231
Range	(2.12 – 20.14)	(24.87 – 36.77)	(731 – 1810)	(4.56 – 28.30)	(27.41 – 43.13)	(1025 – 1832)
TOTAL BODY						
Prone (1,2)	15.04 ± 5.48	67.70 ± 6.62	3824 ± 524	26.93 ± 9.04	78.94 ± 8.59	4307 ± 510
Mid-prone (1,2)	15.02 ± 5.52	67.74 ± 6.70	3810 ± 524	26.97 ± 8.99	78.93 ± 8.57	4294 ± 505
Range	(5.55 – 32.91)	(52.9 – 78.44)	(2516 – 5088)	(10.51 – 43.09)	(60.69 – 92.22)	(3360 – 5134)

Mean ± sd *$p < 0.05$ significantly different from prone.

Table 5 iDXA precision for regional and total body composition parameters and scan mode with the hands in prone and mid-prone positions.

	Standard (n=23)			Thick (n=15)		
	FAT MASS (kg)	LEAN MASS (kg)	BMC (g)	FAT MASS (kg)	LEAN MASS (kg)	BMC (g)
	RMS-SD (%CV)	RMS-SD (%CV)	RMS-SD (%CV)	RMS-SD (%CV)	RMS-SD (%CV)	RMS-SD (%CV)
ARMS						
Prone	0.06 (3.7%)	0.08 (1.0%)	7 (1.2%)	0.07 (3.6%)*	0.17 (1.5%)***	9 (1.4%)
Mid-prone	0.06 (5.2%)	0.13 (1.5%)††	8 (1.3%)	0.09 (3.7%)**	0.21 (2.0%)***	10 (1.6%)
LEGS						
Prone	0.09 (2.6%)	0.24 (1.0%)	10 (0.7%)	0.15 (2.2%)**	0.33 (1.2%)*	10 (0.6%)
Mid-prone	0.09 (1.7%)	0.20 (0.9%)	6 (0.4%)	0.11 (1.6%)	0.26 (0.9%)***†	9 (0.6%)
TRUNK						
Prone	0.17 (2.4%)	0.36 (1.2%)	12 (0.9%)	0.28 (2.2%)*	0.40 (1.2%)	17 (1.2%)
Mid-prone	0.18 (2.6%)	0.26 (0.9%)††	14 (1.1%)	0.33 (2.7%)*	0.32 (0.9%)**††	25 (1.8%)**
TOTAL BODY						
Prone	0.18 (1.1%)	0.25 (0.4%)	11 (0.3%)	0.29 (1.2%)*	0.44 (0.6%)***	19 (0.5%)**
Mid-prone	0.17 (1.3%)	0.20 (0.3%)†	14 (0.4%)	0.26 (1.2%)*	0.33 (0.4%)***	24 (0.5%)**

* $p < 0.05$; **$p < 0.001$; ***$p < 0.0001$ significantly higher than standard scan mode. †$p < 0.05$; ††$p < 0.01$ significantly different from prone.