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Comparison of Multiple Methods of Body Composition Estimation with Military Circumference-Based Equations in Active Duty Service Members: A Cross-Sectional Study

Original Research

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Abstract
Introduction: The Department of Defense circumference-based equations (CBEs) are a field-expedient method to estimate body composition, but often disputed as inaccurate. The purpose of this study was: compare the agreement between CBEs, bioelectrical impedance (BIA), and dual-energy x-ray absorptiometry (DXA) and determine if abdominal circumference (AC) is an effective screening tool to estimate %BF.
Methods: Percent body fat (%BF) was estimated with DXA as the reference standard. Bland-Altman analyses and one-way analysis of variance were used to compare body composition methods. Bivariate regressions were used to analyze if AC was a good predictor of DXA-estimated android fat and %BF.
Results: Estimations of %BF were 4.2% and 0.7% lower in CBEs compared to DXA in men and women, and 3.4% and 3.2% lower in BIA compared to DXA in men and women, respectively. AC was highly correlated with %BF determined by DXA in males (R^2=0.69, p<0.001) and females (R^2=0.56, p<0.001).
Conclusions: Compared to DXA, CBEs exhibited lower %BF estimates in males and BIA provided lower %BF in males and females. Given the strong correlation between AC and %BF determined by DXA, AC may be deemed a cost-effective and field expedient screening method of body composition estimation in this population.

Key Words: DXA, BIA, abdominal circumference

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Introduction

The Department of Defense (DoD) seeks to recruit and retain on active duty individuals capable of upholding military standards, such as high levels of physical performance, mental agility, leadership, and professional military appearance. Body composition affects both physical performance and professional military appearance and has been assessed in Service Members (SMs) since 1864.[1,2] A height and weight table is a simple screening tool that has been used in the U.S. military since 1917 to estimate body composition and the associated health risks, initially used to identify underweight and malnourished SMs.[1,2] In contrast, today an unprecedented prevalence of obesity exists in both the United States civilian and military populations, affecting the medical readiness of SMs.[3,4] Being over-fat increases the risk of musculoskeletal injury and cardio-metabolic diseases.[5-7] In a study of more than 7,000 Army trainees, those exceeding body fat standards were 47% more likely to experience a musculoskeletal injury and had 49% higher healthcare utilization, thus, impacting training costs and completion of service obligation.[5]

The current DoD standard to estimate body composition in SMs requires circumference measurements in conjunction with circumference-based equations (CBEs). The CBEs incorporate height and weight with circumference measurements to determine body composition. Currently, measurements are conducted for women at the neck, the point of minimal circumference of the waist, and the largest protrusion of the buttocks, and for men, at the neck and navel.[8] Circumference-based equations require minimal equipment and training, are considered valid, and considered by the DoD as the most feasible method for determining body composition amongst a large force.[9] The Air Force is currently the only service that requires an abdominal circumference (AC) measure, in addition to height and weight, for their bi-annual fitness test, arguing that an AC measure serves as a useful screening tool for body fat and associated health risks.[10] Other services only utilize circumference measures if a SM exceeds the screening standard set by height and weight tables. The accuracy of CBEs has often come into question amongst SMs with the development of new technologies and methods for determining body composition, such as dual-energy x-ray absorptiometry (DXA) and multi-frequency bioelectrical impedance analysis (BIA).[11]

Dual-energy x-ray absorptiometry is widely considered the reference standard for determining body composition.[12-16] Dual-energy x-ray absorptiometry has shown a low standard error of estimate for predicting bone mineral density (1.8%) and lean and fat mass (1.5% for both).[12] Limitations of DXA—such as expense, immobility, time required for each scan, training required for personnel administering DXA and x-ray exposure (although small)—may hinder its feasibility to become the DoD standard for body composition assessment.[12,13,15,17,18]

Bioelectrical impedance has also become a popular method for determining body composition; it is relatively simple to use, inexpensive and highly portable.[12] Bioelectrical impedance is considered a reliable method to determine %BF; however, it has been shown to underestimate %BF in those who are overweight and obese, and may not be accurate for large epidemiological studies.[15,17,19] Hydration status and electrolyte balance affect accuracy of BIA.[19] There are different types of BIA which may differ in their accuracy and reliability. A more expensive, but more accurate BIA, is an eight-point multi-frequency BIA, which was used in this study. The standard error of measurement in males is 1.76% BF, and for females is 2.17% BF.[12]

With new technology and methods for determining body composition, in conjunction with the anecdotal lack of trust by SMs in the accuracy of the DoD's current method, a comparison of these three methods is warranted. If methods are highly correlated, interchangeable use within the military may be defensible, which would reinforce the use of the current, field-expedient method of circumference measurements with CBEs. If the methods vary considerably in their results, perhaps the current method used by the DoD should be re-evaluated given body composition changes of the military population since first introduction and validation of CBEs in 1998.[20,21] The purpose of this study was to: 1) determine the agreement between body composition estimation methods and 2) assess the predictive ability of AC to determine %BF and android fat as estimated by DXA.

Methods

Participants

Male and female participants included non-pregnant, Active Duty SMs over 18 years of age located in San Antonio, TX, recruited using informational flyers distributed to local military leadership and recruitment briefs around the installation (Fort Sam Houston, TX. Written informed consent was obtained prior to participation in addition to a DXA safety waiver for female participants due to potential pregnancy and x-ray exposure.

A total of 95 SMs were enrolled in the study and were predominantly Caucasian, junior officers (i.e., ranks of Second Lieutenant to Captain), ranging from 21-50 years of age as outlined in **Table 1**. The sample consisted of a total of 47 males (age 32.9 ± 7.2 years; weight 82.9 ± 7.7 kg; BMI 26.5 ± 2.5 kg/m^2) and 48 females (age 28.7 ± 6.0 years; weight 68.7 ± 9.9 kg; and BMI 24.5 ± 3.3 kg/m^2). The Regional Health Command-Central Institutional Review Board approved all human subject procedures.

Protocol

Testing was conducted between 6:00am and 5:00pm. Participants were instructed to refrain from strenuous physical activity for eight hours prior to their appointment, refrain from eating large meals two hours prior to their appointment and arrive euhydrated. If BIA results indicated under or over-hydration,

Table 1. Descriptive Participant Characteristics

Characteristic	Mean ± SD	
Age	30.8 ± 6.91	
BMI (kg/m^2)	25.5 ± 3.08	
	n	**%**
Sex		
Male	47	49.5
Female	48	50.5
BMI Category		
18.5-24.9 kg/m^2	43	45.3
25-29.9 kg/m^2	46	48.4
≥ 30 kg/m^2	5	5.3
Ethnicity		
White	76	80
Black	6	6.3
Hispanic	10	10.5
Other	3	3.2
Pay Grade	(n=63)	
E1-E9	11	17.5
O1-O3	40	63.5
O4-O6	12	19

% = percent expressed to the nearest tenth decimal; BMI = body mass index and is categorized according to standard ranges of normal weight, overweight, and obese classifications; n=number of participants; E=enlisted personnel pay grades, junior enlisted (n=2), senior enlisted (n=9), enlisted personnel were consolidated due to small sample size of junior enlisted personnel; O= officer pay grades. Officer pay grades stratified by O1-O3 to represent "company grade" officers and O4-O6 to represent "field grade" officers. The pay grade of 32 participants was not reported.

a re-test occurred at a different date. All participants were assessed in their service-specific physical fitness uniform consisting of shorts and t-shirt with shoes removed.

Weight was measured to the nearest 0.1 kilogram (kg) using a calibrated digital scale. Height was measured to the nearest 0.1 centimeter (cm) using a stadiometer. Three body composition assessments were collected, utilizing circumference measurements with CBEs, BIA, and DXA. From all three methods %BF, fat mass (FM), and fat-free mass (FFM) were derived. DXA also allowed for android fat determination, which was used in bivariate regressions. Research staff were trained to collect data in accordance with standard operating procedures.

Circumference measurements with CBEs were collected in accordance with Army Regulation (AR) 600-9: The Army Body Composition Program, with minor alterations.[22] The alterations included the use of a Gulick tape measure to provide standardized tension, an additional AC collected for females at the navel, and initial measurements were collected in centimeters rather than inches to improve accuracy. Bioelectrical impedance was conducted using an eight-point multi-frequency BIA, the InBody Bioelectrical Impedance Analyzer (model 770, Biospace America, Cerritos, CA) and DXA was conducted using the Lunar Prodigy Advance DXA bone densitometer (model 8743, GE, Madison, WI), both in accordance with manufacturer's instructions.

Statistical Analysis
Demographic descriptive statistics were conducted with data reported as frequency and percent for categorical variables and mean ± standard deviation (SD) for continuous variables. One-way ANOVA and Tukey's multiple comparisons test compared the three methods to determine which pairs differed. Multiple Bland-Altman analyses determined the mean difference, variance, and potential bias of CBEs or BIA methods compared to DXA. Bivariate regression compared body composition methods as well as determined the association between AC, android fat and overall %BF. Statistical analysis was conducted using JMP Pro 14 (SAS Institute Inc. Cary, NC) with an *a priori* alpha set at 0.05. A sample size estimation was conducted *a priori* using G*Power (Universität Kiel, Germany) with a recommended sample size of 66 participants.

Results
A one-way ANOVA with Tukey's test determined that there was a significant difference between the three methods for %BF, but not overall FM or FFM. Other significant differences between paired methods are reported in **Table 2**.

Table 2. Body Composition Comparison of Participants Dichotomized by Gender, Fat-Free Mass and Fat Mass.

	CBEs	**BIA**	**DXA**	***p*-value**	*p-value CBEs vs BIA*	*p-value CBEs vs DXA*	*p-value BIA vs DXA*
%BF-All	23.03 ± 8.10	22.20 ± 8.29	25.46 ± 8.12	0.018**	0.763	0.102	0.017**
%BF-Males	17.22 ± 4.87	18.00 ± 6.71	21.37 ± 6.91		0.815	0.004**	0.026**
%BF-Females	28.73 ± 6.43	26.31 ± 7.65	29.47 ± 7.21		0.224	0.866	0.079
FFM (g) -All	17383 ± 6786	16846 ± 7127	18580 ± 6874	0.212	0.855	0.459	0.198
FFM (g) -Males	68449 ± 5344	67706 ± 6705	64446 ± 10933		0.895	0.044**	0.124
FFM (g) -Females	48474 ± 4370	50065 ± 5440	48102 ± 8662		0.447	0.957	0.295
FM (g) -All	17383 ± 6786	16846 ± 7127	18580 ± 6874	0.212	0.855	0.459	0.198
FM (g) -Males	14477 ± 4990	15100 ± 6365	17290 ± 6525		0.869	0.063	0.184
FM (g) -Females	20229 ± 7143	18557 ± 7477	19844 ± 7038		0.495	0.963	0.658

BIA=bioelectrical impedance analysis; CBE=circumference-based equation; DXA=dual x-ray absorptiometry; FM=fat mass; FFM=fat-free mass; g=grams; %BF=percent body fat. Data presented as mean ± standard deviation. One-way ANOVA was used to determine statistical significance between factors. ** denotes significant difference ($p<0.05$)

Bland-Altman analyses determined that CBEs underestimated %BF on average by 4.2% for men with a 95% confidence interval (CI) between 3.1% and 5.2% and 0.7% for females with a 95% CI between -0.4% and 1.9% **(Figure 1).**

These analyses also demonstrated that at over 22% BF for men via DXA, CBEs underestimate %BF to a greater degree than at lower %BF. This same bias was not demonstrated in females. Bioelectrical impedance was also shown to underestimate %BF when compared to DXA. Bioelectrical impedance underestimated %BF by 3.4% for men with a 95% CI between 2.5% and 4.3%, and by 3.2% for women with a 95% CI between 2.4% and 3.9% **(Figure 2).**

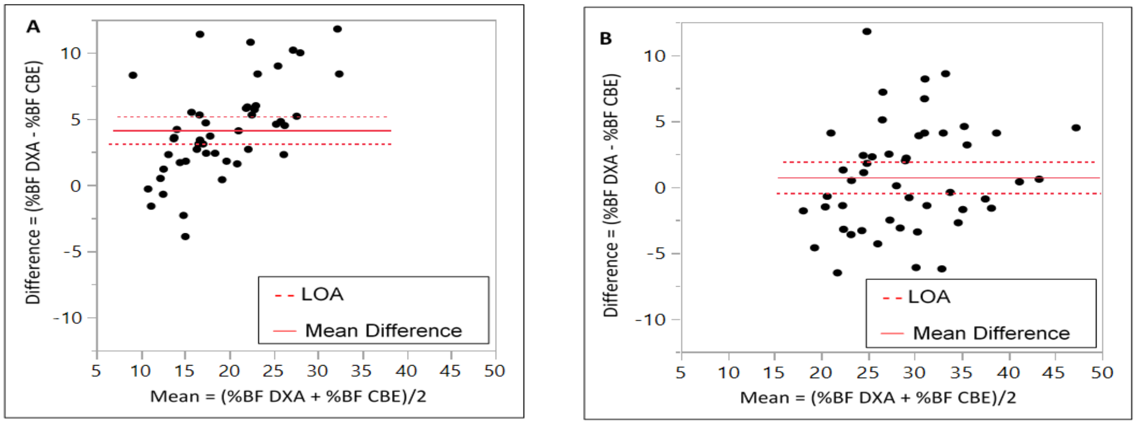

Figure 1.

Agreement analysis of DXA vs. CBEs with data expressed as total body fat (%) by sex. Bland-Altman plot; n=95; "A" represents males and "B" represents females. * would indicate a significant difference between the methods (p<0.001). Limits of agreement (LOA) and mean difference are plotted by the horizontal lines on the figure; %BF = percent body fat; DXA= dual-energy x-ray absorptiometry; CBE = Department of Defense circumference-based equations.

At higher %BF, BIA did not demonstrate underestimation of %BF as observed with CBEs, indicating that BIA may be more consistant between sexes and across varying %BF levels.

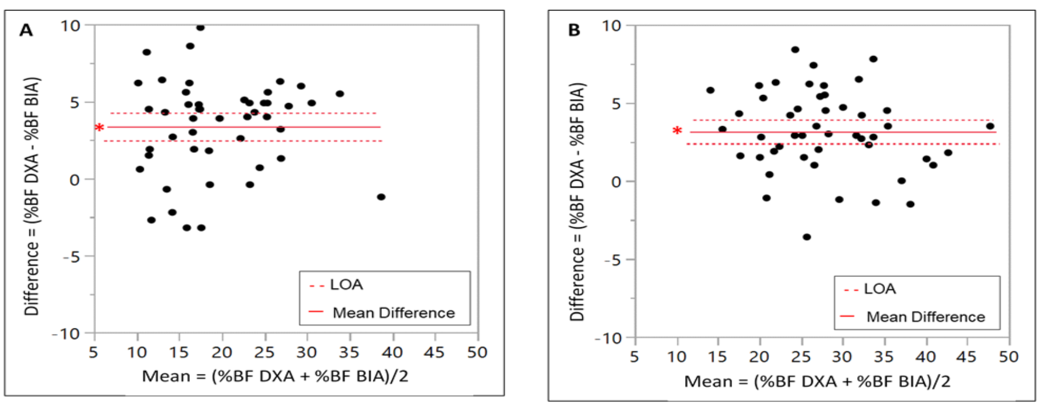

Figure 2.

Agreement analysis of DXA vs. BIA with data expressed as total body fat (%) by sex. Bland-Altman plot; n=95; "A" represents males and "B" represents females. * indicates a significant difference between the methods (p<0.001). Limits of agreement (LOA) and mean difference are plotted by the horizontal lines on the figure.; %BF = percent body fat; DXA= dual-energy x-ray absorptiometry; BIA= bioelectrical impedance analysis.

A bivariate regression determined that AC was highly correlated with android fat measured by DXA in males (R^2 = 0.82, p<0.001) and females (R^2=0.87 p<0.001) **(Figure 3).** A bivariate regression also determined that AC was highly correlated with %BF determined by DXA in both males (R^2=0.69, p<0.001) and females (R^2=0.56, p<0.001) **(Figure 4)**.

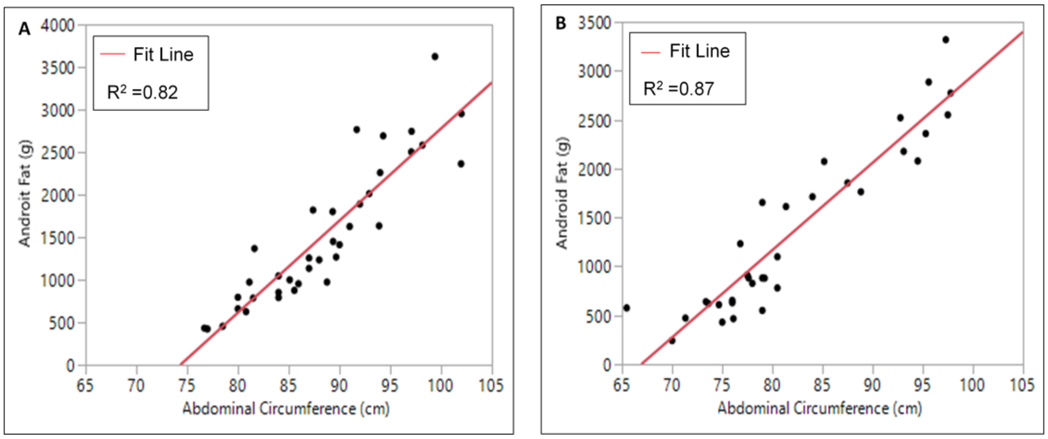

Figure 3.

Correlation between abdominal circumference and android fat via DXA. n = 70; "A" represents males (n=37) and "B" represents females (n=33). Abdominal circumference was significantly correlated with android fat as determined by DXA ($p<0.001$) for both males and females.

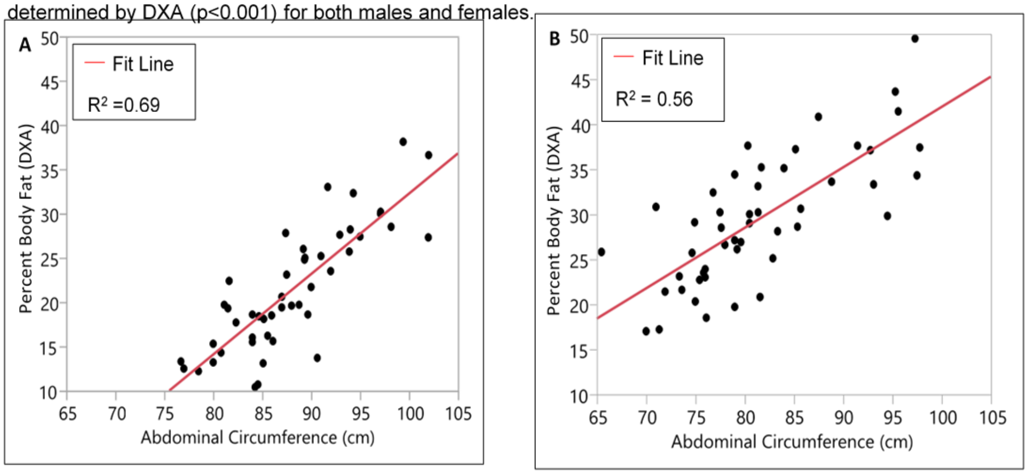

Figure 4.

Correlation between abdominal circumference and total body fat (%) via DXA by sex. n=95; "A" represents males and "B" represents females. Abdominal circumference was significantly correlated with total percent body fat as determined by DXA ($p<0.001$) for both males and females

Discussion

Our results demonstrate that on average, CBEs underestimate %BF when compared to DXA. This is contrary to many SMs beliefs that the CBEs tend to penalize them unfairly.[11,23] This distrust, though, may lie not in the method itself, but in the assessors. To our knowledge, no previous studies have strictly evaluated inter-rater reliability of CBEs across military units or installations. Anecdotal reports, without existing literature to verify, suggests high variability circumference measurement results from one assessor to another. It is possible, however, for poor measurement technique to be remedied to reduce measurement error.

All three methods, if conducted properly, are considered valid methods of body composition estimation and vary in our sample by no more, on average, than five %BF.[9,13,18,24] The portability, ease of use, and relatively low cost of CBEs and BIA may make these methods more intriguing for a military setting than DXA. Dual-energy x-ray absorptiometry and BIA allow for segmental analysis and provide more in-depth body composition results than CBEs.[12,25] This may be beneficial given the DoDs current movement towards a human performance optimization model. The Army has recently implemented the Holistic Health and Fitness (H2F) System, moving healthcare teams from distant clinics into close proximity to Soldiers' day-to-day training and operations. Given this, BIA will be more accessible as it is a part of the

H2F team's equipment list. The segmental analysis of BIA would allow for multiple members of inter-professional healthcare teams (dietitians, physical therapists, strength and conditioning coaches, occupational therapists, and others) to utilize body composition results to assess progress in training, rehabilitation, and reconditioning. Although the military does not have access to large-scale DXA analysis, BIA may prove to be a useful tool for body composition estimation in this population.

Abdominal circumference is another potentially valid, field-expedient method that should be considered for regular body composition screening across military services. An AC measurement is currently used by the U.S. Air Force as a component of their bi-annual fitness test, but not in other services.[10] Our results support previous research with a high positive association of AC with android fat and overall %BF.[26,27] A recent study demonstrated that soldiers may be enrolled in the Army body composition program only after they well-exceed allowable body fat limits.[28] Regular screening with AC could allow for early detection of SMs who may be over-fat and enable earlier access to resources and intervention.

There were some limitations in this study. Our sample was not distributed between officers and enlisted SMs in a manner that represents the overall military services. Eighty-one percent of our sample were officers and 19% were enlisted SMs, compared to the military population comprised of 82% enlisted and 12% officers.[29] Our sample was also 80% white/Caucasian and 51% female, whereas the total United States military is 65% white/Caucasian and 21% female.[30] It should be noted, the original development of CBEs used a four-compartment model, which eliminates a systematic difference in body fat content estimation associated with ethnicity.[9] Additionally, the cross-sectional nature of our study is a limitation. Having participants complete repeated measures on multiple days may have improved accuracy.

Future studies should focus on determining the inter-rater reliability of CBEs across military units, services, and installations. Body composition results are an important factor in SMs careers and overall military retention. Given the importance of CBEs to a SMs career, the goal should be to use a highly reliable tool that can be consistently employed across the entire military. Further investigation into the feasibility of utilizing BIA and AC in this population is warranted. The overall cost, portability, ease of use, timeliness, depth of results, and reliability should be considered when determining the most feasible method of body composition estimation for military SMs.

Conclusion

Our results support that CBEs and BIA underestimate %BF compared to DXA. In males, both CBEs and BIA significantly underestimated %BF; in females, only CBEs significantly differed from BIA. However, BIA demonstrated more consistent results across sexes and %BF ranges. Despite statistical significance, the clinical significance of the differences in results between body composition methods is debatable.

As the DoD moves towards a proactive approach to healthcare with focus on performance optimization, and the Army significantly improves Soldier access to clinicians through H2F, the current method of CBEs for determining body composition should be further evaluated, as it provides limited results, and demonstrated bias to underestimate %BF, specifically at higher body fat levels. Comparing the interrater reliability of these methods is key. Our results also support that an AC measure should be considered for regular screening of SMs. An AC measure, given high correlation with %BF, may better predict and prevent overweight and obesity in this population as the current height and weight screen conducted bi-annually (other than in the Air Force) does not estimate %BF and CBEs do not include an AC measure for females.

Media-Friendly Summary

The purpose of this study was to compare three methods of body composition assessment. Many individuals that have a connection to the military have heard of the oft-maligned 'tape test'. This test involves measuring the circumference of the neck and stomach, plus hips in females, and is the current Department of Defense standard for determining body composition in Service Members. With new body composition assessment technology such as Bioelectrical Impedance Analysis (BIA) and Dual-Energy X-ray Absorptiometry (DXA), the tape test's validity is often questioned in military circles. Our study aimed to compare the tape test and BIA to the gold-standard of DXA in addition to investigating if an abdominal circumference (AC) measure may serve as a useful percent body fat (%BF) screening tool. Our results demonstrate that the tape test underestimated %BF by 4.2% in males and 0.7% in females compared to DXA, and that AC was highly correlated with %BF.

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Conflict of Interest
None

Disclaimers
1. The investigators have adhered to the policies for protection of human subjects as prescribed in 45 CFR 46.
2. The views expressed are those of the author(s) and do not reflect the official policy of the Department of the Army, the Department of Defense or the U.S. Government.

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