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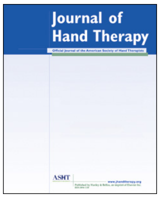

Wrist weight-bearing tolerance in healthy adults

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ABSTRACT

Study Design: Cross-sectional.
Introduction: No information is available in the literature regarding the amount of weight-bearing tolerance in a normal human wrist.
Purpose of the Study: To establish the normal limits of human wrist weight-bearing tolerance and to determine if gender, age and height are predictors of this weight-bearing tolerance.
Methods: A sample ($N = 465$) of healthy adults ages 18-64 completed a questionnaire indicating their gender, age range and height. Subjects were instructed in performing a wrist weight-bearing tolerance test using a calibrated analog scale. The amount of pressure that the subject was able to apply to the scale in 3 independent trials was recorded and analyzed.
Results: A strong positive correlation was found between average weight- bearing values achieved through the right and left hands for the subjects of this study, $r(463)= .97$, $P < .001$. A 2-way analysis of covariance revealed main effects for both gender (20.9, 95% CI [15.7, 26.0] pounds, $P < .001$) and age ($F(4, 454) = 6.143$, $P < .001$, partial $\eta^2 = .051$). The highest weight-bearing tolerance was observed in males and individuals 25-34 years of age. Multiple regression analysis affirmed that gender, height and age categories of 45-54 and 55 to 64 were all statistically significant predictors of wrist weight-bearing tolerance, $P < .01$.
Discussion: These results establish normal wrist weight-bearing tolerance values and demonstrate that gender, age and height are predictors of this weight-bearing tolerance.
Conclusion: These results could allow identification of pathologies associated with wrist instability.

Introduction

Wrist instability and pain are common problems reported by patients.[1-3] These impairments have a large differential diagnosis, including but not limited to the instability of the distal radioulnar joint (DRUJ), stress fracture, carpal bone instability, or carpal bone fracture.[4-6] Many of these pathologies are often not visible with plain radiographs and require expensive imaging modalities such as magnetic resonance imaging, magnetic resonance angiography, or cineroentgenography.[3,7-10]

The DRUJ acts as a functional unit that allows pronosupination, hand positioning, and axial load transmission.[11] The inherently unstable bony anatomy of the DRUJ is functionally supported by soft tissue, including the triangular fibrocartilage complex (TFCC), radioulnar ligament, pronator quadratus, interosseous membrane, joint capsule, and extensor carpi ulnaris.[12-16] Numerous pathologies that disrupt the stability of the DRUJ have been identified, and not surprisingly, the ability to perform activities of daily living independently is decreased in individuals that have DRUJ instability.[12,17] However, there is currently no clinical tool available to objectively measure wrist stability.

A quantitative wrist weight-bearing study was previously performed using the upper limbs from twelve fresh-frozen cadavers.[18] This cadaveric study examined the axial load transmission of force through the radius and ulna in upper limbs that showed no pathology, as well as upper limbs that were surgically altered by the researchers. Force transmission tolerated by these specimens was monitored using a custom-made device fitted with strain gauges. Results from this cadaveric study indicated that both the radius and ulna were involved in force transmission through the DRUJ.[18] Additionally, the study reported that the anatomic integrity of the DRUJ was essential for normal force transmission through the joint.[18]

The push-off test (POT) is a quantitative wrist weight-bearing test that has appeared in the literature.[19] This test was shown to be a valid and reliable assessment of wrist weight-bearing capability through an injured arm. However, the sample size ($N = 22$) was limited to individuals with current wrist or elbow injuries. The authors were able to demonstrate a moderate relationship between POT performance and DASH scores. More recently, the reliability

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and validity of the POT were confirmed with a larger sample size ($N = 50$).[20]

The "press test" is a qualitative test for the diagnosis of DRUJ instability due to the presence of a TFCC tear.[21] This test is 100% sensitive, and due to its simplicity, it has become a standard in the clinical identification of TFCC tears. Using the basics of the press test, one of the authors (WM) developed a quantitative wrist weight-bearing test that had the subject exert weight through an extended elbow and wrist onto a scale. This modification allowed the clinician to not only identify the amount of pressure required to promote pain during wrist weight-bearing but also allowed monitoring of wrist healing during subsequent rehabilitation.[22] After years of using this test in clinical practice, it was observed that wrist weight-bearing appeared to be dependent on gender, age, and height.

No information is available in the literature regarding the amount of weight-bearing tolerance in a normal human wrist. The purpose of this study is twofold. First, to establish the normal limits of human wrist weight-bearing tolerance and second, to determine if gender, age, and height are predictors of this weight-bearing tolerance. This normative data would provide clinicians with reference values for the reliable objective assessment of wrist stability and subsequent rehabilitation.

Methods

The Institutional Review Board of the (FWA00004149) has approved this research project #14-091 and deemed it exempt. All individuals that participated in this study signed an informed consent document.

Journal policy and ethical obligation require reporting that one of the authors of this paper (WM) is the patent owner of a company that manufactures a unique wrist brace known as the WristWidget. This business may be positively affected by the results reported in this manuscript.

For this cross-sectional study, subjects ($N = 465$) were a worldwide sample of convenience recruited by advertising the study with a poster displayed in public locations, including schools, churches, and coffee shops. Wrist weight-bearing tolerance testing was performed by two of the authors during their travels to Hilo, Hawaii; San Diego, California; Bangkok, Thailand; Normandy, France; Paris, France; Rotterdam, Netherlands; Belgium; Norwich, England; Barcelona, Spain; Cape Town, South Africa; Geneva, Switzerland; and Porto, Portugal; Melbourne, Australia.

Subjects were asked to complete a questionnaire to indicate their gender, age range, height, and medical eligibility for the study. The ten-year age ranges used in the questionnaire were arbitrarily selected at the start of the study. Included in the study were healthy adults ages 18 to 64 who were able to provide informed consent. Exclusion criteria included current wrist pain, history of wrist fracture, currently treated with oral or injected cortisone, previously diagnosed with Rheumatoid Arthritis or Lupus, pregnancy, or actively breastfeeding infants.

Wrist weight-bearing tolerance was determined using a quantified version of the "Press Test" (Fig. 1).[21] Subjects were standing while they placed their palm on a calibrated analog scale with the long finger pointing to 12:00 o'clock to prevent radial or ulnar rotation. While ensuring that the elbow and the wrist were in full extension, they were next instructed to push down on the scale to the point of maximum capacity. This pressure was not sustained for any length of time. The maximum amount of pressure that the subject was able to apply to the scale was measured in pounds or kilograms and recorded. This process was repeated twice providing three trials. This wrist weight-bearing tolerance test was then repeated with the contralateral hand. All recorded data were used in the statistical analyses.

Statistical analysis was performed using SPSS version 26. Descriptive statistics were used to calculate subject demographics. Since original weight-bearing data was gathered in pounds or kilograms, all numbers were converted to pounds to allow data

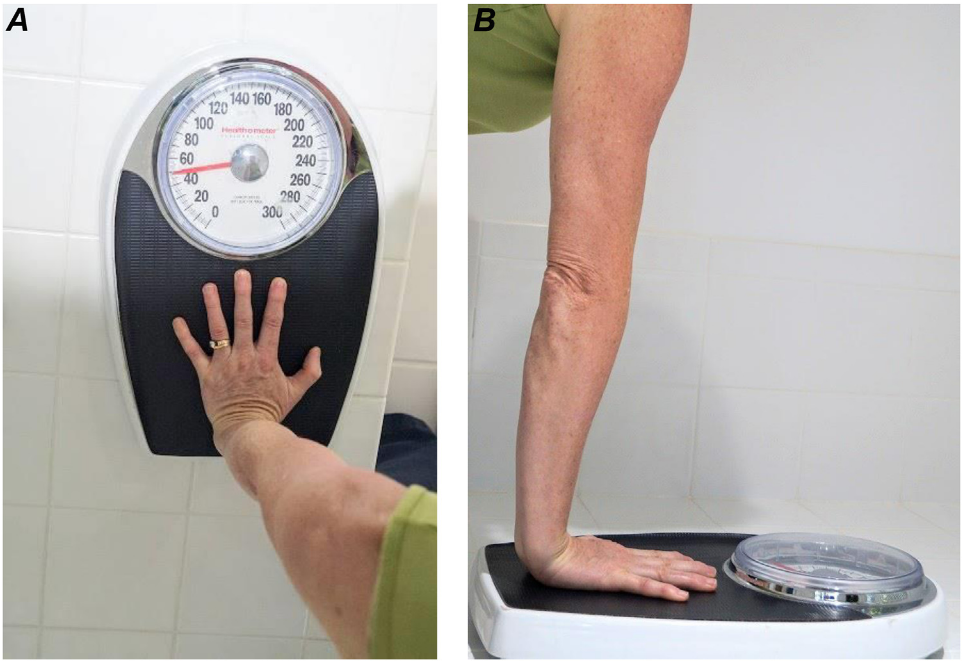

Fig. 1. Performing the Wrist Weight-Bearing Test. Place a nondigital scale on a solid surface. While standing, place the palm of the hand to be tested in the center of the scale with the fingers extended and the long finger pointing to 12 o'clock as shown in panel (**A**). Ensure that the wrist is located under the elbow and that both are in a fully extended position as shown in panel (**B**). Place as much pressure on the scale as you can tolerate without pain and record the highest number displayed on the scale. This test is repeated three times and the average of the three weight-bearing values is recorded. The process is then repeated with the contralateral upper extremity.

comparison. A Pearson's product-moment correlation was run using the means from the three different weight-bearing trials for both the right-hand and the left-hand of the same individuals.

Means and adjusted means for wrist weight-bearing tolerance were calculated with a 2 × 5 analysis of covariance (ANCOVA) using height in inches as the continuous independent variable.

Multiple regression analysis was performed to allow estimation of wrist weight-bearing tolerance based on age, gender, and height. Visual inspection was used to determine if the assumptions of homoscedasticity and multicollinearity were met. There was the independence of residuals, as assessed by a Durbin–Watson statistic of 2.090. There was no evidence of multicollinearity, as assessed by tolerance values greater than 0.1.

Results

Subjects ($N = 465$) were approximately equally distributed with respect to gender and age. The study participants ranged in height from 59 to 77 inches ($M = 67$, $SD = 3.6$) (Table 1).

Analysis of the Pearson's product-moment correlation revealed a linear relationship between the two variables, and there were no outliers (Fig. 2). There was a statistically significant strong positive correlation between average weight-bearing values achieved through the right-hand and left-hand for the subjects of this study, $r\,(463) = .97$, $P < .001$.

A linear relationship was observed between subject height and wrist weight-bearing tolerance for all possible combinations of the independent variable groups composed of gender and age ranges (data not shown). There was homogeneity of regression slopes as determined by a comparison between the two-way ANCOVA model with and without interaction terms, $F(9, 445) = 1.01$, $P = .431$. There was homoscedasticity within groups, as assessed by plotting the studentized residuals against the predicted values for each group (data not shown). There were no outliers in the data, as assessed by no cases with studentized residuals greater than ±3 standard deviations. There were no leverage or influential points, as assessed by leverage values and Cook's distance, respectively. Studentized residuals were normally distributed, as assessed by Shapiro–Wilk's test ($P = .193$).

Means, adjusted means, standard deviations, standard error, and confidence intervals for wrist weight-bearing tolerance are detailed in Table 1. There was no statistically significant interaction between gender and age on wrist weight-bearing tolerance, while controlling for height, $F(4, 454) = 0.953$, $P = .433$, partial $\eta^2 = .008$. For this reason, the main effects analysis was performed for both gender and age.

Gender elicited a statistically significant difference in adjusted marginal mean wrist weight-bearing tolerance for males (82.5 pounds) compared to females (61.6 pounds), 20.9, 95% CI [15.7, 26.0] pounds, $P < .001$. There was also a statistically significant main effect of age, $F(4, 454) = 6.143$, $P < .001$, partial $\eta^2 = .051$. Adjusted marginal means for pounds of wrist weight-bearing tolerance in the 25 to 34 years old age category (77.9 pounds) was higher than the 18 to 24 and the 35 to 44 years old age categories (76.6 and 73.7 pounds respectively). These respective differences were not statistically significant, 1.22 (95% CI, −7.4 to 9.8) pounds, $P = 1.00$, and 4.11 (95% CI, −3.8 to 12.0) pounds, $P = 1.00$. Additionally, the adjusted marginal means for wrist weight-bearing in the 25 to 34 years old age category was also higher than the 45 to 54 and 55 to 64 years old age categories (69.4 and 62.8 pounds respectively). However, these respective differences were found to be statistically significant, 8.5 (95% CI, .6-16.4) pounds, $P = .026$, and 15.1 (95% CI, 5.4-24.7) pounds, $P < .001$.

Wrist weight-bearing tolerance was predicted from gender, age, and height using multiple regression analysis. R^2 for the overall model was 37.6%, with an adjusted R^2 of 37.1%. Gender, age, and height statistically significantly predicted wrist weight-bearing tolerance, $F\,(4, 460) = 69.408$, $P < .001$. Gender, height, and age categories of 45 to 54 and 55 to 64 years old were all determined to be statistically significant predictors, $P < .01$. Regression coefficients and standard errors are reported in Table 2.

Table 1
Subject demographics

Variable	All subjects ($N = 465$)	
Gender	Females	259 (56%)
Age range	18-24	75 (16%)
	25-34	125 (27%)
	35-44	102 (22%)
	45-54	105 (23%)
	55-64	58 (12%)
Height	67 (3.6)	Range: 59-77

Values reported as frequency (%) for categorical variables and mean (SD) for continuous variables.

Discussion

Reports of pain while the wrist is placed in an extended weight-bearing position is a common patient report encountered by clinicians.[1-3] A variety of pathologies, including but not limited to fracture, arthritis, radioulnar ligament injuries, extensor carpi ulnaris instability, and TFCC injury either alone or in combination may be responsible for this pain.[2,12,13,15,17,23] The amount of wrist weight-bearing pressure tolerated before the onset of pain could be identified, quantified, and followed through the rehabilitation process if the normative values of human wrist weight-bearing tolerance were known. The present study details the normal weight-bearing tolerance of the human wrist and reveals that gender, age, and height are predictors of this weight-bearing tolerance.

Healthy individuals aged 18 to 64 years of age participated by providing maximum pressure through their unilateral palm onto a scale with their ipsilateral wrist and elbow fully extended (Fig. 1). Normal wrist weight-bearing tolerance values were identified through this procedure. Since the right and left wrists of an individual are capable of tolerating similar amounts of force, weight-bearing tolerance through one upper extremity could be used to identify injury in the contralateral upper extremity (Fig. 2). Furthermore, if both wrists were injured, then approximate weight-bearing tolerance values for any individual could be estimated from either the normative data tables or the linear regression equation (Tables 2 and 3). In contrast to this, the information provided by the POT studies is useful for identifying impairment of weight-bearing ability of a single wrist when the contralateral wrist is intact.[19,20] The POT is not particularly useful for individuals that have injured both of their wrists or do not have an uncompromised contralateral side for comparison.

The present study defines values for normal wrist weight-bearing tolerance and reveals that these values are dependent on gender, age, and height. The dependence of wrist weight-bearing tolerance on these three variables may be due to normal changes in bone mineral density or bone quality. A study involving healthy males and females determined that males have a higher bone mass and skeletal size even when they are matched for age, height, weight, and BMI.[24] The fact that males have a higher bone mass than females lends credence to the idea that wrist weight-bearing tolerance may be related to bone quality since males have a higher wrist weight-bearing tolerance than females. Additionally, a study examining changes in bone mineral density in healthy individuals 25 to 44 years of age revealed that age-related decrease in bone

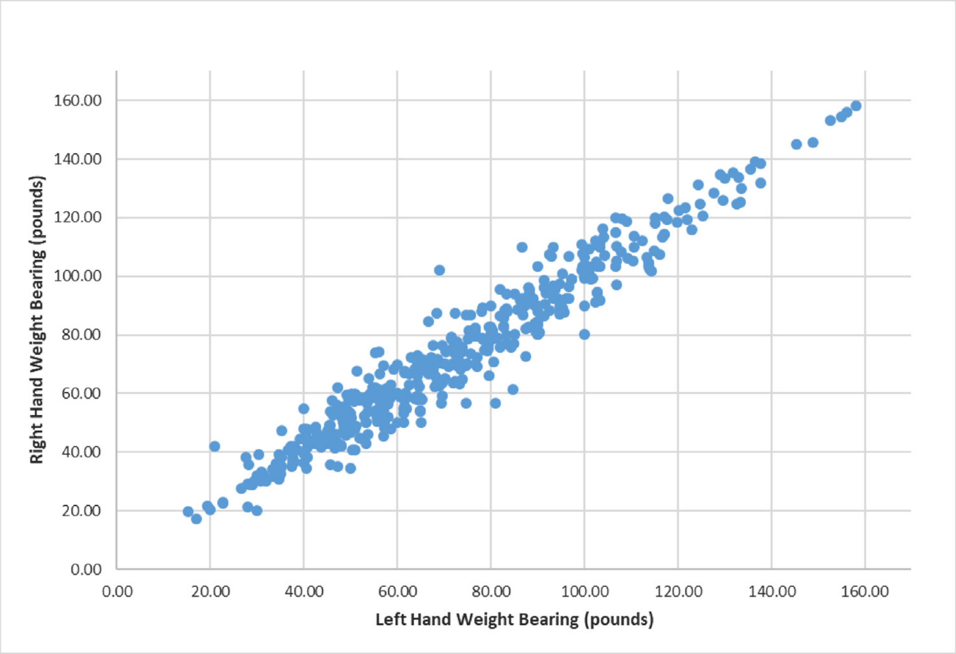

Fig. 2. Scatter plot correlating weight-bearing tolerance through the *right* and *left* wrists. Weight-bearing tolerance values obtained from the *right* wrist are plotted against the weight-bearing tolerance value obtained from the *left* wrist of the same subject. All values are reported in pounds.

quality started around 36 years of age for both men and women.[25] This finding is consistent with the wrist weight-bearing results that reveal a decrease in wrist weight-bearing capacity in both men and women starting in the 35 to 44 years old age category. Another study aimed to examine the relationship between bone quality and height and found that bone quality was lower in individuals with shorter stature.[26] Findings from the present study reveal that wrist weight-bearing tolerance is also greater in taller individuals.

This wrist weight-bearing tolerance study opens multiple avenues for future research. Since the present study identified gender, age, and height as variables responsible for 37% of wrist weight-bearing tolerance, additional studies will be aimed at identifying predictors responsible for the other 63%. Ideas for these other variables include medications, weight, bone density, muscular strength of upper extremity and scapular muscles, and consistent performance of activities that promote upper extremity loadings such as gymnastics and yoga. Future studies will also aim to use this simple weight-bearing test in the differential diagnosis of wrist pain with upper extremity weight-bearing. For example, it may be possible to differentiate a fracture from a TFCC injury based on the presence or absence of pain with a brace that stabilizes the wrist joint.[22] Finally, another future area of study will be to determine if following changes in wrist weight-bearing tolerance of injured wrists during subsequent rehabilitation could allow a clinician to assess the rate of healing.

Table 2
Means, adjusted means, standard deviations, standard errors, and confidence intervals for wrist weight-bearing

Gender	Age range	Weight-bearing norms		95% confidence interval	
		M (SD)	M_{adj} (SE)	Lower	Upper
Male	18-24	96.1 (26.2)	90.6 (3.5)	83.8	97.4
	25-34	92.4 (24.5)	87.8 (2.9)	82.2	93.5
	35-44	87.0 (25.8)	82.0 (3.3)	75.6	88.5
	45-54	81.2 (23.5)	78.2 (3.4)	71.6	84.8
	55-64	75.8 (23.4)	73.9 (4.6)	65.0	82.9
Female	18-24	59.6 (22.9)	62.7 (3.6)	55.6	69.8
	25-34	64.3 (17.6)	67.9 (2.7)	62.6	73.1
	35-44	62.8 (18.6)	65.5 (2.8)	59.9	71.0
	45-54	57.2 (16.6)	60.6 (2.7)	55.3	65.8
	55-64	47.1 (14.5)	51.7 (3.6)	44.7	58.6

M = mean, SD = standard deviation, M_{adj} = adjusted mean, SE = standard error. All values are listed in pounds.

Study Limitations

There are multiple limitations to this wrist weight-bearing norms study worth noting. Numerous nondigital scales were used to measure wrist weight-bearing tolerance throughout the course of data collection, and these scales were not calibrated to each other before each weight-bearing trial. This fact may have resulted in small deviations in the actual weight-bearing values recorded. When performing the weight-bearing test, the elbow and wrist were monitored to ensure full extension; however, the position of the scapula during the actual test was not noted. It is possible that subjects with scapular winging would present with a decreased

Table 3
Summary of multiple regression analysis

Variable	B	SE_B	β
Intercept	26.32	25.048	
Gender	−20.3	2.535	−0.385[a]
Height	1.674	0.356	0.229[a]
55-64	−13.79	3.023	−0.174[a]
45-54	−6.63	2.373	−0.106[a]

B = unstandardized regression coefficient; SE_B = standard error of the coefficient; *β* = standardized coefficient.
The equation for estimating wrist weight-bearing tolerance = (26.316) + (−20.31*gender) + (1.674*height) + (−13.791*55-64) + (−6.634*45-54). Gender is coded as "0" for males and "1" for females; height is measured in inches; age category is coded as "1" if subject falls into the specified age category and "0" if not.
[a] Indicates $P < .01$.

normal weight-bearing tolerance value. Inclusion and exclusion criteria for this study were well defined, but other diagnoses or medications that were not screened for may have influenced the values obtained for normal wrist weight-bearing tolerance.

Conclusions

The results of this study are the first documented wrist weight-bearing norms for healthy adults. These wrist weight-bearing tolerance values could allow objective identification of pathologies associated with wrist pain and instability.

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