Guidelines for Wrist Posture Based on Carpal Tunnel Pressure Thresholds

Peter J. Keir, McMaster University, Hamilton, Ontario, Canada, **Joel M. Bach,** University of Colorado Health Sciences Center, Aurora, Colorado, and **Mark Hudes** and **David M. Rempel,** University of California, San Francisco, Richmond, California

Objective: To develop work guidelines for wrist posture based on carpal tunnel pressure. **Background:** Wrist posture is considered a risk factor for distal upper extremity musculoskeletal disorders, and sustained wrist deviation from neutral at work may be associated with carpal tunnel syndrome. However, the physiologic basis for wrist posture guidelines at work is limited. **Methods:** The relationship of wrist posture to carpal tunnel pressure was examined in 37 healthy participants. The participants slowly moved their wrists in extension-flexion and radioulnar deviation while wrist posture and carpal tunnel pressure were recorded. The wrist postures associated with pressures of 25 and 30 mmHg were identified for each motion and used to determine the 25th percentile wrist angles (the angles that protect 75% of the study population from reaching a pressure of 25 or 30 mmHg). **Results:** Using 30 mmHg, the 25th percentile angles were 32.7° (95% confidence interval [CI] = 27.2°–38.1°) for wrist extension, 48.6° (37.7°–59.4°) for flexion, 21.8° (14.7°–29.0°) for radial deviation, and 14.5° (9.6°–19.4°) for ulnar deviation. For 25 mmHg, the 25th percentile angles were 26.6° and 37.7° for extension and flexion, with radial and ulnar deviation being 17.8° and 12.1°, respectively. **Conclusion:** Further research can incorporate the independent contributions of pinch force and finger posture into this model. **Application:** The method presented can provide wrist posture guidelines for the design of tools and hand-intensive tasks.

INTRODUCTION

Wrist posture is one of the factors considered in estimating risk for developing distal upper extremity disorders in workplace studies. Nonneutral wrist posture may be a risk for hand and wrist symptoms, tendon-related disorders, and carpal tunnel syndrome (National Institute for Occupational Safety and Health [NIOSH], 1997). The general rule is to avoid sustained deviation from a neutral wrist posture. Gross categories for classifying wrist postures have been incorporated into risk assessment tools (Keyserling, Stetson, Silverstein, & Brouwer, 1993; McAtamney & Corlett, 1993; Moore & Garg, 1995), but the physiological basis for selecting specific wrist postures for these categories is limited. There is little consensus on the range of wrist angles that are appropriate for tasks and, the inverse, which angles should be avoided. It would be useful for designers to have physiologically based guidelines for wrist posture when designing or evaluating tasks and tools.

Epidemiologic studies have identified nonneutral wrist postures as risk factors for wrist tendinitis and carpal tunnel syndrome (Amano, Umeda, Nakajima, & Yatsuki, 1988; Armstrong & Chaffin, 1979; Bystrom, Hall, Welander, & Kilbom, 1995; DeKrom, Kester, Knipschild, & Spaans, 1990; Kuorinka & Koskinen, 1979; Loslever & Ranaivosoa, 1993; Luopajarvi, Kuorinka, Virolainen, & Holmberg, 1979; Moore & Garg, 1994; Stetson, Silverstein, Keyserling, Wolfe, & Albers, 1993; Tanaka et al., 1995). These studies used self-reported wrist postures or measured wrist postures with goniometers or observational methods. Each study used different criteria for categorizing wrist posture. For example, a study using self-reports included questions about duration of

Address correspondence to David M. Rempel, U.C. Ergonomics Program, University of California, San Francisco/Berkeley, 1301 S. 46th St., Building 163, Richmond, CA, 94804; david.rempel@ucsf.edu. ***HUMAN FACTORS,*** Vol. 49, No. 1, February 2007, pp. 88–99.

exposures to "extended" or "flexed" wrists (DeKrom et al., 1990). An observational study used flexion-extension angle categories of 0° to 25°, 25° to 45°, and >45° and ulnar deviation angle categories of <10°, 10° to 20°, and >20° (Moore & Garg, 1994). A workplace screening tool, the Rapid Upper Limb Assessment (RULA), classifies extension-flexion in three categories, with 0° being "neutral," whereas radioulnar deviation is considered only "if present" (McAtamney & Corlett, 1993). The Strain Index (Moore & Garg, 1995) uses a 5-point graded system with verbal anchors developed from a prior study (Moore & Garg, 1994). To simplify posture analysis, the workplace checklist of Keyserling et al. (1993) classified the wrist angle simply as "obvious" flexion, extension, or radioulnar deviation. Based on the wide variability of approaches, it is evident that a basis and criteria for classifying wrist postures may be useful to researchers and practitioners.

Using human and animal studies, sustained, elevated carpal tunnel pressure (CTP) and the resultant ischemia has been identified as a likely mechanism in the development or aggravation of carpal tunnel syndrome (CTS; Keir & Rempel, 2005; Rempel, Dahlin, & Lundborg, 1999; Rempel & Diao, 2004). There are other potential pathways to injury, such as mechanical compression (Dyck, Lais, Giannini, & Engelstad, 1990); however, the following discussion is limited to presenting the basis of the pressure-ischemia-injury hypothesis.

Patients with CTS typically have CTP above 30 mmHg in a neutral wrist posture, whereas in healthy controls the pressures are typically well under 10 mmHg (Gelberman, Hergenroeder, Hargens, Lundborg, & Akeson, 1981; Hamanaka, Okutsu, Shimizu, Takatori, & Ninomiya, 1995; Luchetti et al., 1989; Okutsu, Ninomiya, Hamanaka, Kuroshima, & Inanami, 1989; Seradge, Jia, & Owens, 1995; C.-O. Werner, Elmqvist, & Ohlin, 1983). Paresthesia and changes in neuronal conduction amplitude and velocity occur when CTPs are experimentally elevated to 30 mmHg or more (Lundborg, Gelberman, Minteer-Convery, Lee, & Hargens, 1982). Thus, there is evidence of a pressure threshold in humans above which the probability of nerve impairment increases.

The short- and long-term effects of nerve compression have been investigated in animal studies and support the concept of a pressure threshold for injury. Compression pressures as low as 20 mmHg can decrease blood flow inside the nerve; pressures of 30 mmHg can reduce nutrient transport down the nerve axon (Lundborg, Myers, & Powell, 1983; Rydevik, Lundborg, & Bagge, 1981). Brief, low-pressure (30 mmHg) compression can cause vascular permeability and may lead to a persistent edema in the nerve (Lundborg et al., 1983). Small inflatable cuffs have been used in animal models to assess the long-term effects of nerve compression. Pressures of 30 and 80 mmHg applied to a nerve for only 2 hr led to an immediate edema, followed much later by axonal degeneration and fibrosis. A pressure of 10 mmHg caused little of these effects (Dyck et al., 1990; Powell & Myers, 1986). These studies support a pressure threshold for nerve injury at or just below 30 mmHg.

In humans, there is a strong link between hand and wrist posture and pressure. Many studies have evaluated the effects of various forearm and hand postures on CTP in healthy participants. CTP is influenced by wrist posture (Keir, Bach, & Rempel, 1998a; Keir, Wells, Ranney, & Lavery, 1997; R. Werner, Armstrong, Bir, & Aylard, 1997), forearm posture (Rempel, Bach, Gordon, & So, 1998; R. Werner et al., 1997), finger posture (Keir, Bach, & Rempel, 1998a), and fingertip force (Rempel, Keir, Smutz, & Hargens, 1997; Keir, Bach, & Rempel, 1998b). CTP increases with forearm rotation in either direction from 45° of pronation (Rempel et al., 1998; R. Werner et al., 1997), with finger postures of full finger extension or flexion (e.g., a fist; Cobb, An, & Cooney, 1995; Keir et al., 1998a), and with wrist deviation from neutral (Keir et al., 1998a; Weiss, Gordon, Bloom, So, & Rempel, 1995).

Knowledge of the relationship between wrist posture and CTP can be used to develop wrist posture guidelines that may protect a certain percentage of the population from CTPs above 30 mm Hg. The threshold of protecting 75% of the population has been used for the development of psychophysically based guidelines on manual materials handling (Snook & Ciriello, 1991), lifting (Snook, 1978), and wrist torques (Ciriello, Snook, Webster, & Dempsey, 2001). Although Snook's (1978) original work found that a worker was three times more susceptible to injury if the task was acceptable to less than 75% of the working population, the "protective" value of including 75% of the population has not yet been established for objective data such as CTP.

In healthy human volunteers, we identified the wrist postures at which the CTPs exceeded pressure thresholds of 25 and 30 mmHg. The goal was to identify the range of wrist angles associated with CTPs of less than 25 and 30 mmHg in more than 75% of the study population.

METHODS

Participants

Thirty-seven healthy participants (19 men and 18 women) were recruited from the University of California (San Francisco and Berkeley) and the surrounding community. Participants had no medical history or physical exam findings of CTS and had a normal nerve conduction of the median nerve at the wrist. The right hand was used in 34 participants and the left hand in 3. The mean age of the participants was 30.5 ± 7.5 years (range 22–50 years). This study was approved by the Committee on Human Research, University of California at San Francisco.

Medical Examination

All participants were interviewed and examined by a physician to confirm that they were free of symptoms and signs of CTS. The examination included (a) evaluation of muscle strength (thumb opposition, interossei, grip) and thenar atrophy; (b) sensation to touch in the hand and fingers; (c) Phalen's and Tinel's signs; and (d) electrodiagnostic study of the median nerve (thenar muscle recording, antidromic sensory conduction between wrist and index finger, and orthodromic short-segment between palm and wrist). The skin temperature of the palm was measured; the hand was warmed if less than 31°C. The findings of the histories, physical examinations, and nerve conduction studies were normal for all participants.

Experimental Setup

CTP was measured using a saline-filled, multiperforated 20-gauge (0.8-mm) catheter (Burron Medical, Inc., Bethlehem, PA) inserted percutaneously into the carpal tunnel and connected to a pressure transducer (Rempel, Manojlovic, Levinsohn, Bloom, & Gordon, 1994). The pressure transducer and carpal tunnel were maintained at the same elevation to ensure consistent pressure readings. The possibility of catheter occlusion was minimized by maintaining a slight positive flow of physiologic saline at a rate of 0.5 ml/hr using a low-flow continuous flush device (Model 42002-02, Sorenson Intraflow II).

A biaxial electrogoniometer (Biometrics Ltd., Gwent, UK) was secured to the dorsum of the hand and wrist to provide continuous measures of radioulnar and extension-flexion angles. Calibration of the device included deviation to known angles as well as identifying a zero or neutral wrist position for each participant. Neutral wrist posture was determined by laying the palmar surface of the hand and forearm on a flat surface with positioning pegs for the elbow, wrist, and middle finger (Weiss et al., 1995). Pressure and angle data were sampled at 40 Hz and stored digitally.

Materials and Task

After insertion of the catheter, the participant was seated with the upper arm hanging vertically at his or her side with the elbow flexed to 90°. The participant was instructed to move the forearm and wrist through a full range of motion, including flexion, extension, radioulnar deviation, pronation, and supination. The posture of lowest pressure was determined during this task (Rempel et al., 1998). Each subsequent task was initiated from this posture of lowest pressure with the metacarpophangeal joint maintained at 45°, fingers relaxed, and the forearm pronated approximately 45°. The participant then progressed through a series of extension-flexion and radioulnar deviation tasks. An extension-flexion task consisted of the participant actively extending the wrist to a comfortable end range of motion, followed by flexing the wrist to a comfortable end range while the radioulnar posture was neutral. This was repeated so that three complete motions, from end range to end range, were performed with each angle being crossed four times. The same procedure was completed in radioulnar deviation with extension-flexion in neutral. The order of testing was the same for all participants; however, an order effect was unlikely because the carpal tunnel pressures returned to the same low levels between tasks.

Data Reduction and Statistical Analyses

A least-squares pressure-angle curve was fit to the data for each participant from the three complete repetitions of the motion. The curve was fit to the mean pressure values at 5° increments of wrist angle for extension-flexion and radioulnar deviation. For each participant, the pressure-angle curve was examined to identify the wrist angle at which pressures of 25 and 30 mmHg were attained. The designation "DNA" was used to denote those participants who "did not attain" the pressure threshold of 25 or 30 mmHg. For analysis purposes, if a pressure threshold was exceeded throughout the range of wrist motion, then a wrist angle of 0° was assigned for that participant. This occurred in 4 individuals, typically at the lower pressure levels (e.g., 25 mmHg).

From these distributions, wrist angles were estimated for the 5th, 10th, 15th, 20th, and 25th percentiles separately for each of the pressures of 25 and 30 mmHg and each of the four motion directions. In the equation

$$\omega_i = \overline{X} + sZ_i' , \quad (1)$$

ω_i corresponds to the wrist angle at the ith percentile (e.g., i = 5th, 10th,…25th, $\overline{X}$ is the mean angle of the distribution, s is the standard deviation of the distribution, and Z_i' is the adjusted z score corresponding to the ith percentile value). The values were selected to compensate for the participants who did not attain the given pressure level because their values could not be accurately placed on the distribution. Therefore, $\overline{X}$ and s are taken from the distribution that does not include participant data classified as DNA, and the Z_i' value was also adjusted. To estimate the 5th percentile of the participant pool in which only 31 of 37 participants (83.8%) achieved the threshold, we used Equation 1 to estimate the 5.97% percentile (5%/0.838) to reflect the reduced number of participants in this distribution. The 5.97% of the reduced data set would correspond to the 5th percentile of the full data set.

Confidence intervals (CIs) were obtained using the following approximation for the variance of omega (ω):

$$\text{var}(\omega) = (1 + Z'^2/2)\, s^2/n, \quad (2)$$

in which n is the number of samples in the distribution. The 95% CI was estimated with the upper limit as $\omega + 2 \times SE(\omega)$ and the lower limit as $\omega - 2 \times SE(\omega)$, in which $SE(\omega) = [\text{var}(\omega)]^{0.5}$).

RESULTS

Mean CTPs pressures are presented by wrist extension-flexion angle (Figure 1) and radioulnar deviation angle (Figure 2). The pressure threshold levels of 25 and 30 mmHg are indicated by horizontal dashed lines. CTPs are more elevated in the direction of extension than flexion. For the radioulnar pressure curve, the pressure increases for

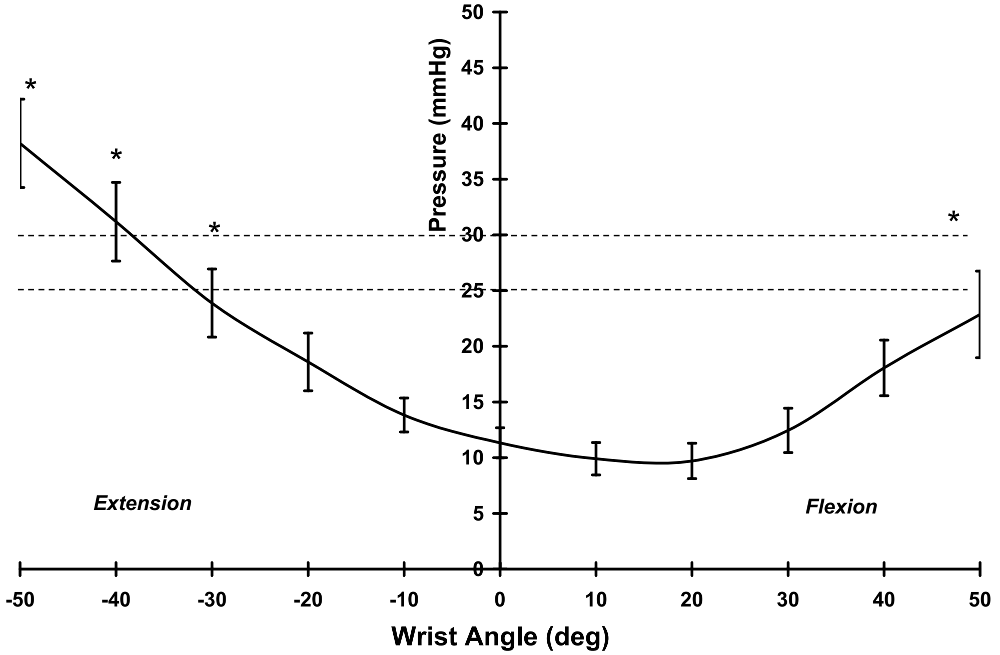


Figure 1. Carpal tunnel pressure (mmHg) versus wrist extension-flexion angle (degrees). Asterisks indicate significant difference from the neutral wrist. Horizontal dashed lines represent threshold levels. $N = 37$.

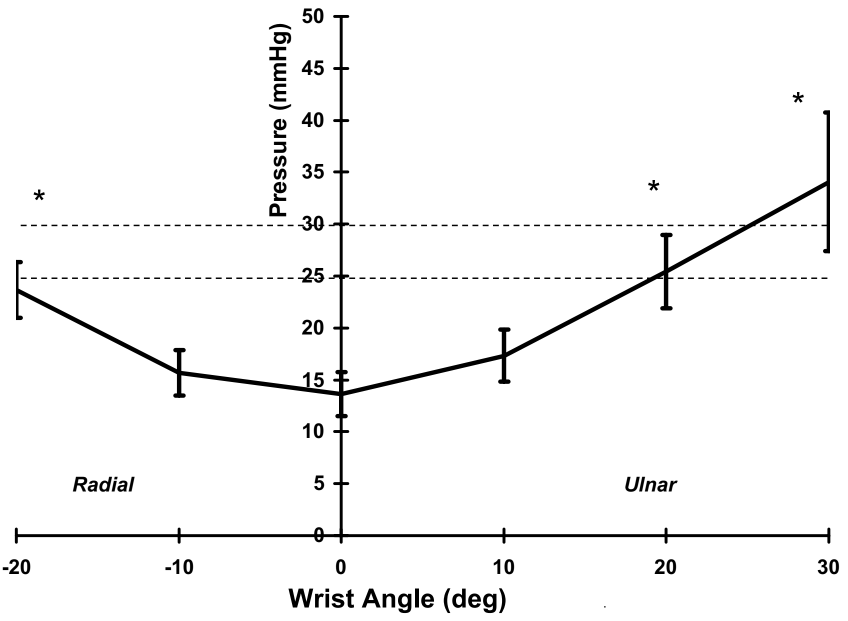


Figure 2. Carpal tunnel pressure (mmHg) versus wrist radioulnar angle (degrees). Asterisks indicate significant difference from the neutral wrist. Horizontal dashed lines represent threshold levels. $N = 37$.

ulnar deviation are similar to radial deviation per 5° interval; however, participants had greater range of motion in the ulnar deviation direction.

The population distribution of wrist angles associated with 25- and 30-mmHg pressure thresholds are presented in Figures 3 and 4. A relatively normal distribution of wrist extension angles is shown in the left panels of Figure 3, with the exception of 9 individuals who did not reach the 30-mmHg pressure level (labeled "DNA" on the figures). With wrist flexion, 25 of the 37 participants did not reach 30 mmHg (Figure 3, bottom right panel). With radial (Figure 4, bottom left panel) and ulnar (Figure 4, bottom right panel) deviation, even fewer individuals reached a CTP of 30 mmHg (26 and 17, respectively). One participant was unable to perform radial deviation; thus there are only 36 data points in the radial deviation data (Figure 4, left panels).

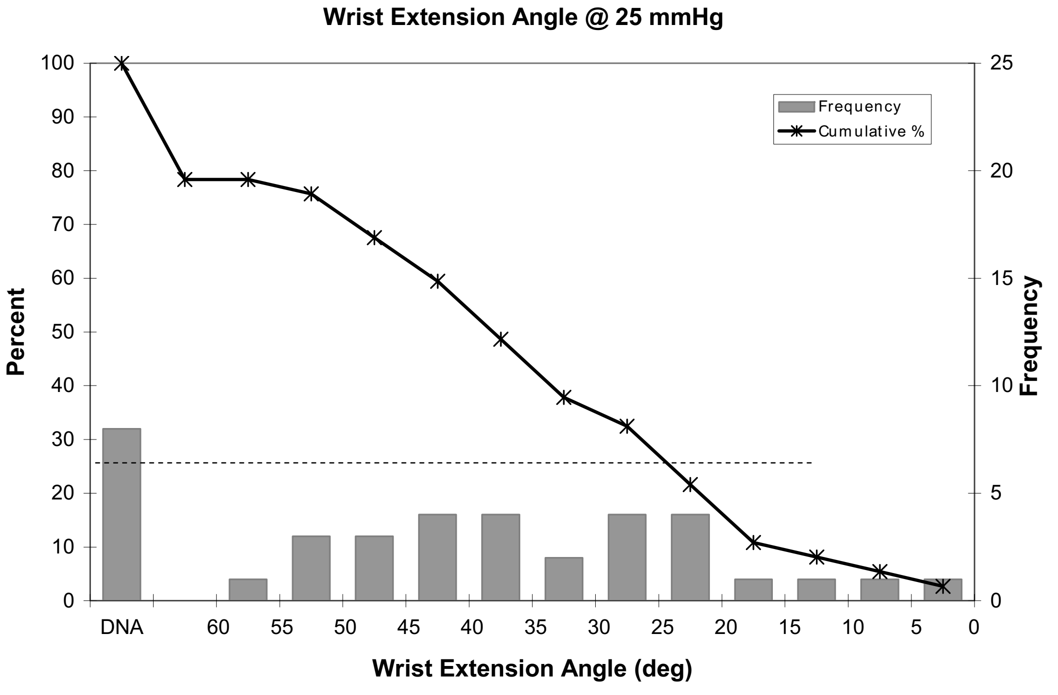
Wrist angles corresponding to the 5th to 25th percentiles were calculated for both the 25- and 30-mmHg pressure thresholds (Table 1). At these wrist angles, 95% to 75% of the study population would have CTPs lower than the pressure thresholds of 25 or 30 mmHg. Discrepancies between the calculated wrist angles and the wrist angles shown in Figures 3 and 4 are attributable to the effects of participants who did not attain the relevant pressure threshold on the calculations.

DISCUSSION

As far as we are aware, this is the first study to systematically identify limits of wrist posture based on CTP thresholds. The findings indicate that in order to prevent mean CTP from exceeding 30 mmHg in 75% of the study population, wrist extension should not exceed 32.7°, flexion should not exceed 48.6°, and ulnar and radial deviation should not exceed 14.5° and 21.8°, respectively. These wrist angles may be interpreted as threshold limit values for wrist angles based on CTP. We also present wrist angles that are more protective of the population, using lower percentiles (5%–20%, protecting 95%–80% of the population, respectively) and a lower critical pressure threshold of 25 mmHg.

A critical pressure of 30 mmHg provides minimal protection from nerve injury (Rempel et al., 1999). In animal models, pressures of 30 mmHg applied to a nerve for 2 hr caused a persistent increase in the pressure inside the nerve, edema, and nerve demyelination (Powell & Myers, 1986). It can be expected that such pressures, if maintained for a prolonged period, will have similar effects on human nerves.

The distribution of CTPs for flexion and extension are different (Figure 3). Over 65% (25/37) of our participants did not attain 30 mmHg during



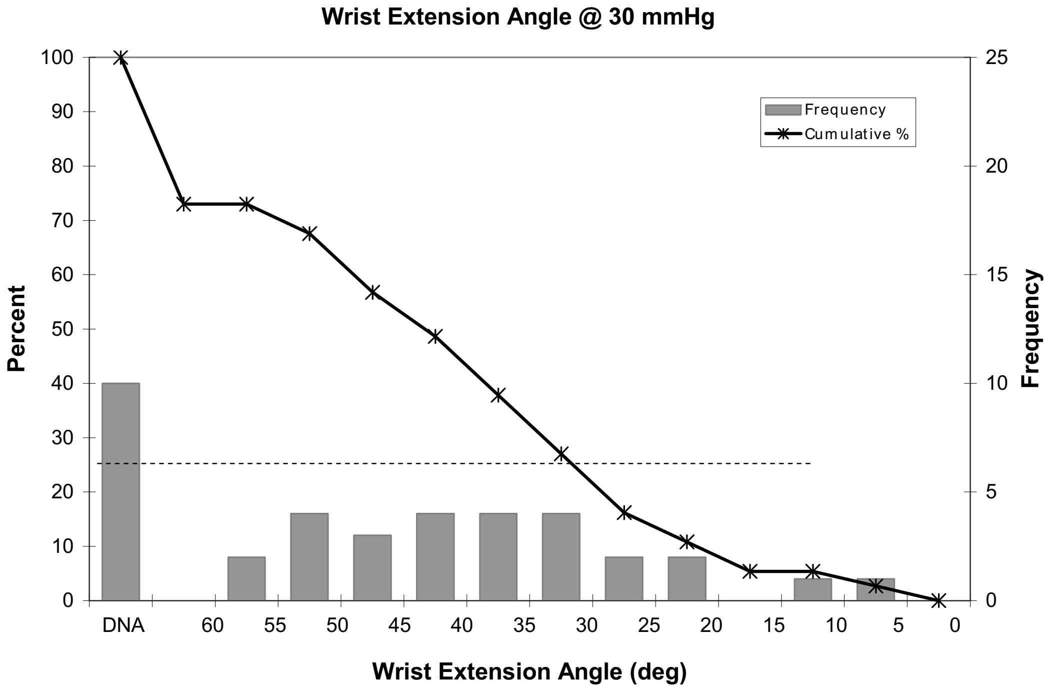
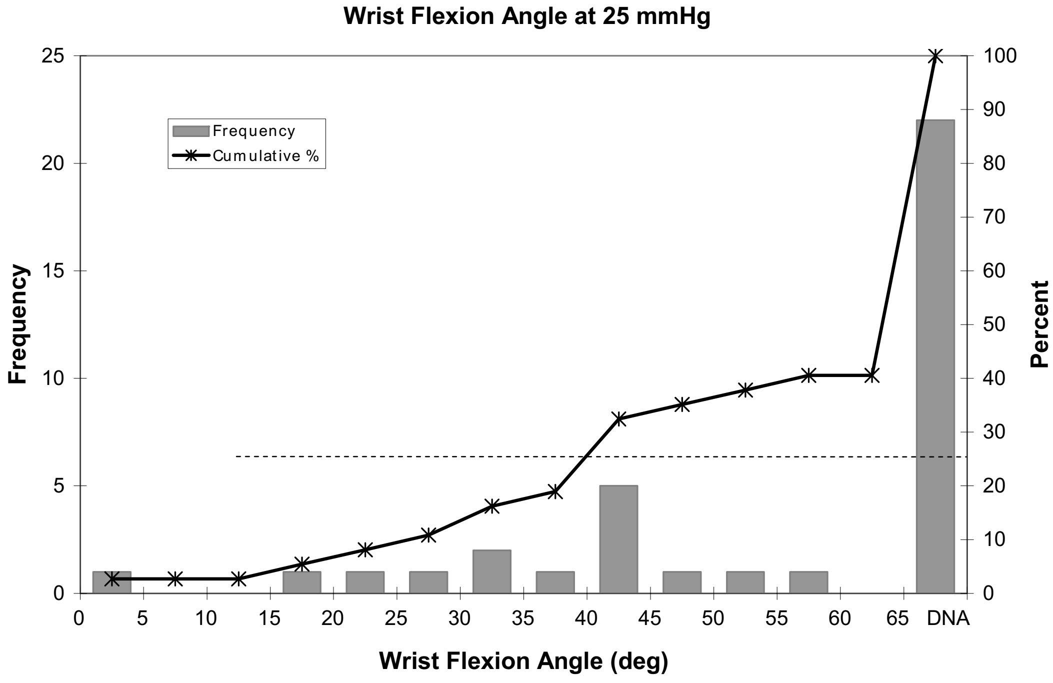


Figure 3. Distribution of wrist flexion and extension angles at which a carpal tunnel pressure threshold of 25 mmHg (top panel on this page, and top panel on the next page) and 30 mmHg (bottom panel on this page, and bottom panel on the next page) occurred. The graphs on this page represent occurrences with wrist extension ($N = 37$), and the graphs on the next page represent the distribution for wrist flexion ($N = 37$). The horizontal lines indicate 25% of the individuals. Participants whose pressure always exceeded the threshold were included in the zero (0) bin, and those whose pressure never reached the threshold are included in the DNA column. Bars represent frequencies, and the lines indicate cumulative percentage.



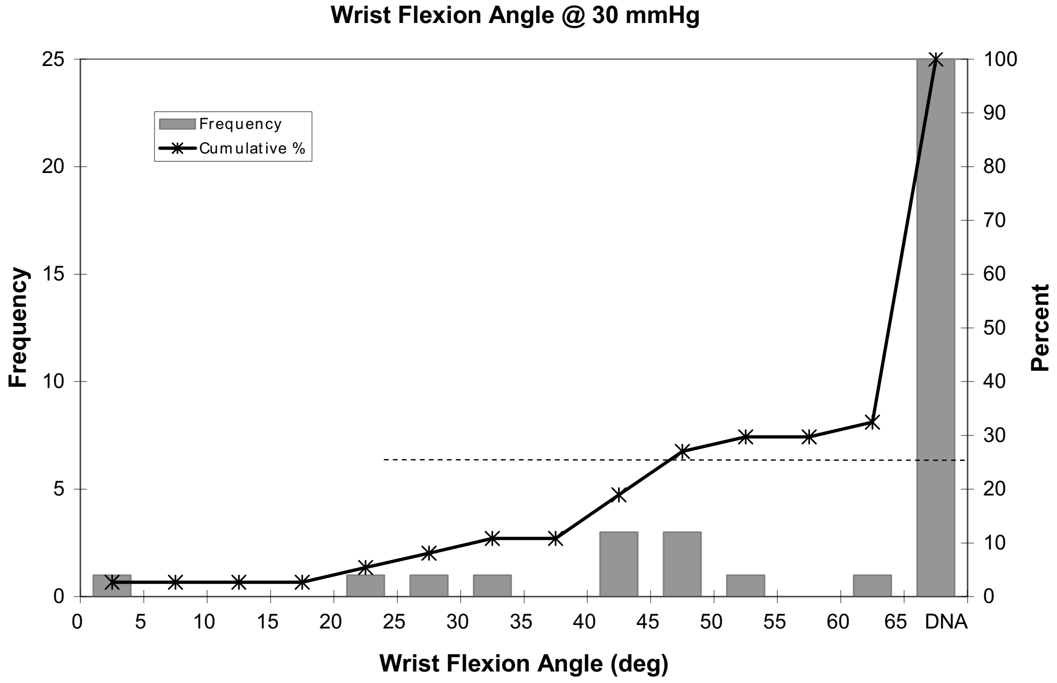


Figure 3 continued.

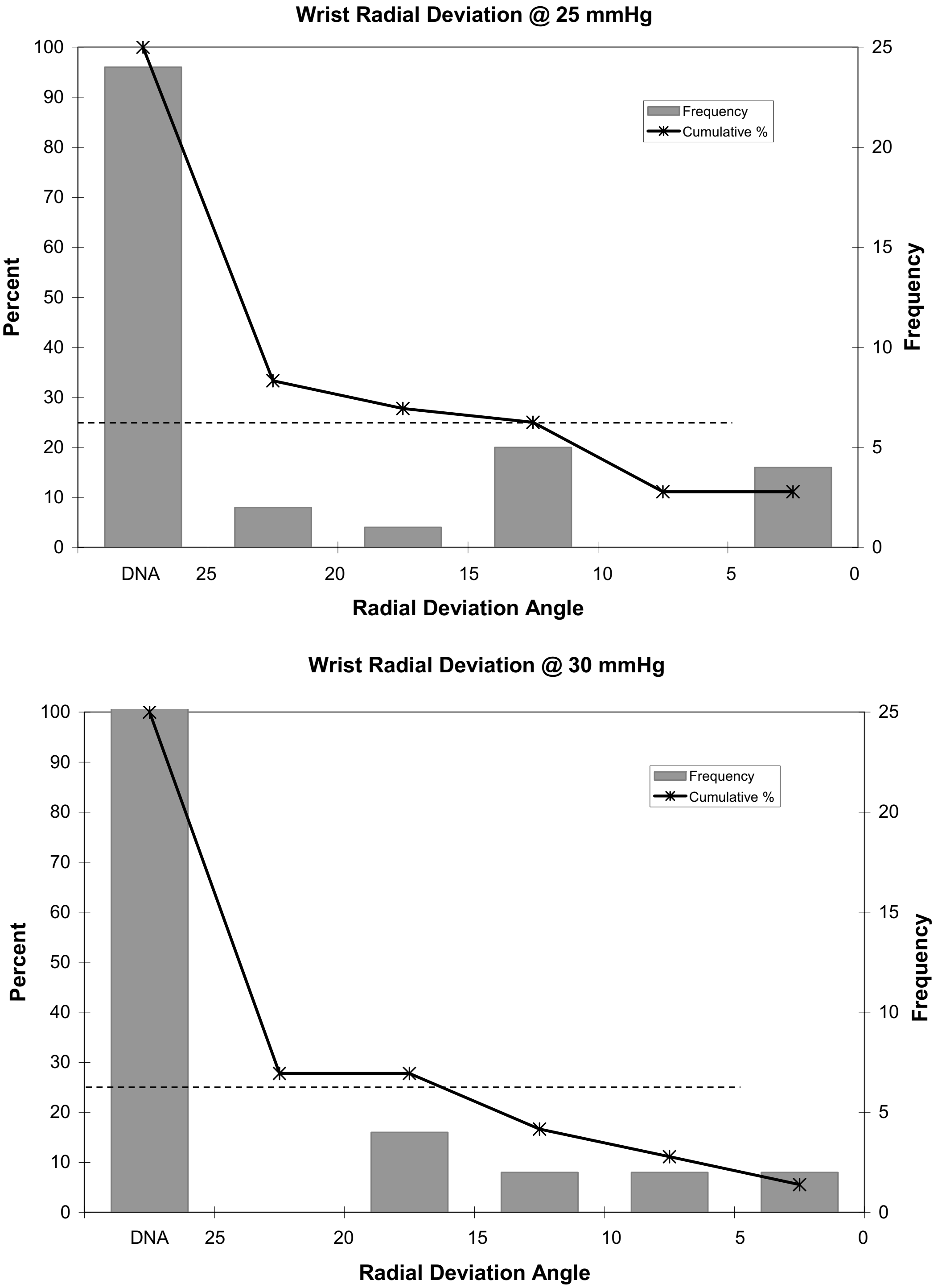


Figure 4. Distribution of wrist radial and ulnar deviation angles at which a carpal tunnel pressure threshold of 25 mmHg (top panel on this page, and top panel on the next page) and 30 mmHg (bottom panel on this page, and bottom panel on the next page) occurred. The graphs on this page represent occurrences with radial deviation ($N = 36$), and the graphs on the next page represent the distribution for ulnar deviation ($N = 37$). The horizontal lines indicate 25% of the individuals. Participants whose pressure always exceeded the threshold were included in the zero (0) bin, and those whose pressure never reached the threshold are included in the DNA column. Bars represent frequencies, and the lines indicate cumulative percentage. Note that the DNA frequency for radial deviation at 30 mmHg is 26 (bottom left).

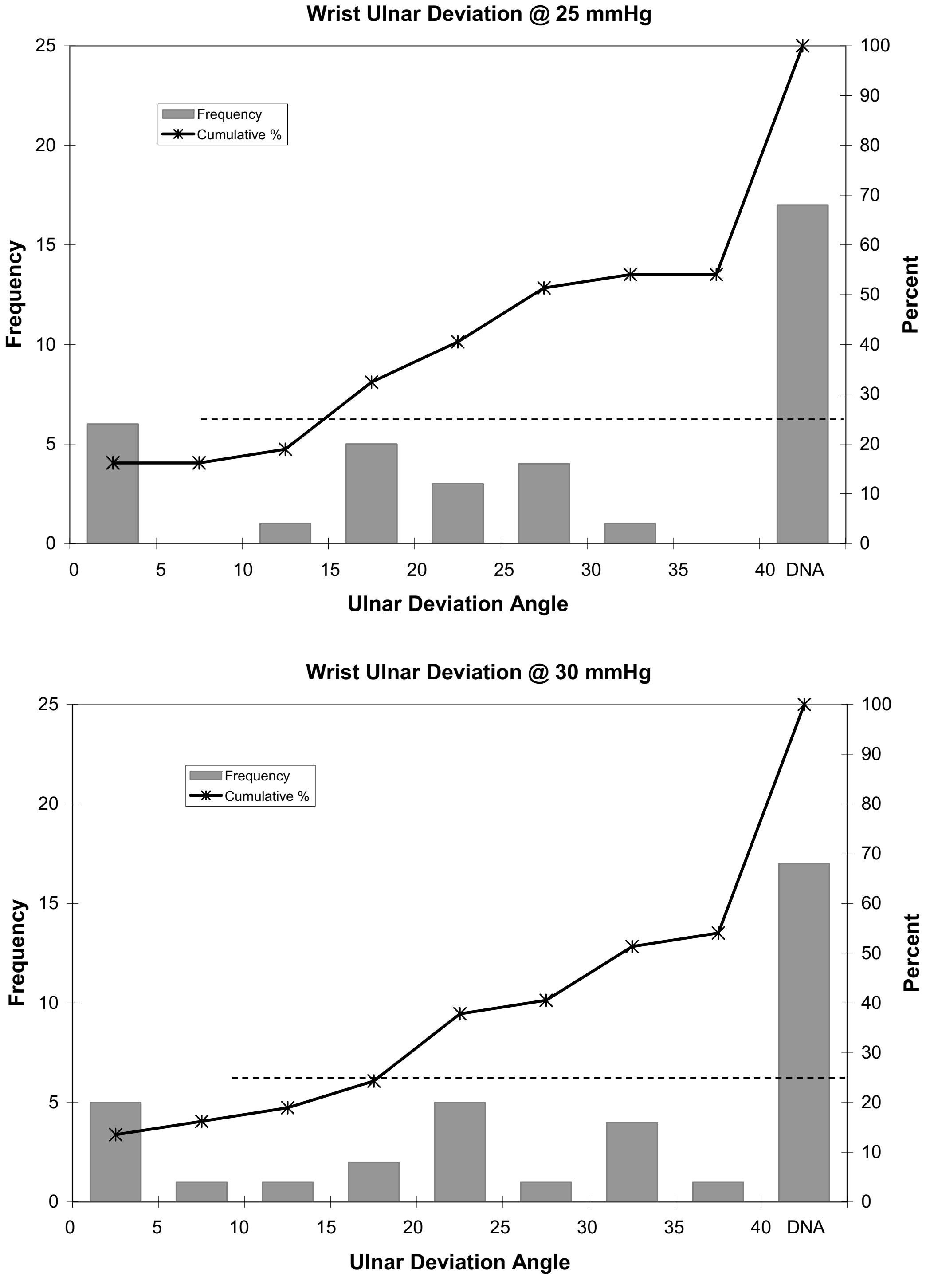


Figure 4 continued.

TABLE 1: Wrist Angles at Which 5% to 25% of the Study Population Attained a CTP of 25 or 30 mmHg

	Threshold Pressure					
	25 mmHg			30 mmHg		
Percentile	Angle (°)	Lower CI[a] (°)	Upper CI[a] (°)	Angle (°)	Lower CI[a] (°)	Upper CI[a] (°)
Wrist Extension (*N* = 37)						
5th	–11.7	–19.4	–3.9	–17.9	–25.6	–10.3
10th	–17.1	–23.8	–10.3	–23.2	–29.9	–16.6
15th	–20.9	–27.1	–14.7	–27.0	–33.1	–20.9
20th	–23.9	–29.7	–18.1	–30.0	–35.8	–24.3
25th	–26.6	–32.1	–21.0	–32.7	–38.1	–27.2
Wrist Flexion (*N* = 37)						
5th	14.9	4.2	25.6	19.0	6.4	31.6
10th	22.5	13.3	31.7	28.1	17.2	38.9
15th	28.1	19.6	36.6	35.1	25.0	45.3
20th	33.0	24.8	41.2	41.6	31.4	51.7
25th	37.7	29.5	46.0	48.6	37.7	59.4
Wrist Radial Deviation (*N* = 36)						
5th	–0.9	–8.3	6.5	–2.7	–10.7	5.3
10th	–6.2	–12.6	0.1	–8.4	–15.3	–1.5
15th	–10.2	–16.1	–4.3	–12.9	–19.4	–6.4
20th	–13.9	–19.8	–8.0	–17.1	–23.7	–10.6
25th	–17.8	–24.0	–11.5	–21.8	–29.0	–14.7
Wrist Ulnar Deviation (*N* = 37)						
5th	–2.5	–9.9	4.8	1.0	–5.6	7.6
10th	2.6	–3.8	9.0	5.6	–0.1	11.4
15th	6.3	0.4	12.1	9.0	3.7	14.2
20th	9.3	3.8	14.9	11.8	6.8	16.8
25th	12.1	6.8	17.5	14.5	9.6	19.4

Note. Wrist extension and wrist radial deviation are defined as negative; wrist flexion and wrist ulnar deviation are defined as positive.
[a]Upper and lower 95th percentile confidence intervals.

flexion, and in wrist extension, 24% (9) did not reach this pressure. For radial deviation 72% (26/36) of individuals did not attain a pressure of 30 mmHg, and for ulnar deviation 47% (17/37) did not (Figure 4).

Some workplace epidemiologic studies and the 1997 NIOSH review found no association between awkward wrist postures and CTS (NIOSH, 1997; Silverstein, Fine, & Armstrong, 1987). This lack of an association with posture may be attributable to the methods by which wrist posture was analyzed in those studies, especially if the studies used peak wrist posture rather than mean posture. Physiologic and animal data suggest that mean posture be the more appropriate indicator of risk. A recent review of the issue by Viikari-Juntura and Silverstein (1999) concluded that forearm, wrist, and finger postures are powerful predictors of CTP, and following the rationale that CTP is an important “pathomechanical step in the development of CTS, postural factors should be considered important risk factors” (p. 175).

The posture guidelines of the current study, based on the 30-mmHg threshold data, can be compared with the categories used in the Strain Index (Moore & Garg, 1995) and RULA (McAtamney & Corlett, 1993). The 25th percentile wrist extension posture of 33° (CI = 27°–38°) from our study falls within the “fair” rating in the Strain Index (26°–40°), and the 5th percentile of 18° (CI = 10°–26°) is virtually identical to the range for “good” posture (11°–25°). All of our wrist extension angles are within or greater than the highest risk category of RULA (15°–30°). For wrist flexion, our 25th percentile angle (49°, CI = 38°–59°) coincides with the “very bad” or worst category in the Strain Index (over 50°), and the 5th percentile angle (19°, CI = 6°–32°) is slightly above "fair" in the Strain Index (16°–30°) and the middle category for RULA (±15°). For radioulnar deviation, only ulnar deviation is considered in the Strain Index, and our 25th percentile angle of 14.5° (CI = 10°–19°) would relate to a rating of "good to fair" (10°–20°) and the 5th and 10th percentiles would be rated "very good" (<10°). No such comparison can be made with RULA, as radioulnar deviation is included "if present" and is not linked to a specific wrist angle. It should be noted that the Strain Index and RULA are screening tools that relate to a wide variety of risk factors and disorders, whereas our guidelines are specific to wrist posture and CTP.

Several limitations of the study should be considered. First, these wrist posture guidelines are based on CTP as a mechanism by which nerve trauma may occur. Other mechanisms may cause CTS (e.g., adhesions, anomalous muscles, pregnancy). Second, the data were collected with the finger and forearm postures close to those associated with the lowest CTP. Deviations from this posture and the addition of fingertip loading will independently increase CTP (Keir et al., 1998b; Rempel, Keir, Smutz, & Hargens, 1997; Seradge et al., 1995). Therefore, the range of wrist postures recommended in this study is likely to be narrower when applied to hand-intensive tasks in the workplace. Third, because the data linking ischemia in the pathophysiology of tendon sheath disorders is not as strong as with CTS (Rempel & Abrahamsson, 2001), it is less certain to what extent these guidelines apply to the prevention of flexor tenosynovitis. Finally, the sample size of 37 may be considered small for generalizing to the general population. However, both the age range (22–50 years) and near-even split of men and women are representative of the working population.

CONCLUSIONS

Identifying wrist postures that will prevent the application of sustained, elevated pressure to the median nerve in the carpal tunnel should be useful for engineers in the design of hand-intensive tasks and hand tools. These wrist posture guidelines can also be used by ergonomists and clinicians to identify tasks that may put the worker at risk for developing or aggravating CTS. The findings may also be useful to researchers in their approach to classifying wrist postures for risk assessment studies. Future research should evaluate pressure thresholds with respect to the combined effects of wrist posture, pinch force, and finger posture.

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Peter J. Keir is an assistant professor in the Department of Kinesiology at McMaster University in Hamilton, Ontario, and an adjunct professor in the Graduate Program in Kinesiology and Health Science at York University in Toronto. He obtained his Ph.D. in biomechanics from the University of Waterloo in 1995.

Joel M. Bach is an associate professor in the Division of Engineering at the Colorado School of Mines in Golden, Colorado, and an assistant professor in the Department of Orthopaedics at the University of Colorado Health Sciences Center, Aurora, Colorado, where he is also director of the Orthopaedic Biomechanics Labs. He obtained his Ph.D. in biomedical engineering from the University of California, Davis, in 1995.

Mark Hudes is a senior statistician, adjunct assistant professor, and lecturer in Department of Nutritional Sciences at the University of California, Berkeley, where he received his Ph.D. in biostatistics in 1982.

David M. Rempel is professor of medicine at the University of California at San Francisco and professor of bioengineering and director of the Ergonomics Graduate Training Program at the University of California, Berkeley. He received his M.D. in 1982 at the University of California at San Francisco.

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