Trichotillometry: the quantitation of hair pluckability as a method of nutritional assessment[1, 2]

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ABSTRACT In protein-calorie malnutrition, particularly kwashiorkor, ease of hair pluckability is frequently observed. In an attempt to quantitate this manifestation of the disease a calibrated mechanical instrument, referred to as a trichotillometer, was devised and used to determine the force required to epilate individual hairs in 17 adult hospitalized patients with evidence of protein-calorie malnutrition and in 16 well-nourished patients. Nutritional status was examined by measuring body weight, triceps skinfold thickness, arm muscle circumference, serum albumin, lymphocyte count, hematocrit, β-carotene, vitamin nutriture, and hair shaft diameter. Average epilation force was significantly lower in the malnourished patients than in the well nourished group (17.0 g ± 11.8 versus 38.2 g ± 11.4, $p < 0.001$), with the lowest mean value found in patients categorized as having kwashiorkor (14.8 g). Plucking force correlated significantly and positively with serum albumin, hair shaft diameter, triceps skinfold, arm muscle circumference, weight, hematocrit, and β-carotene; it did not correlate with vitamin status. In order to determine the effects of acute stress on epilation force a subgroup of 18 patients was evaluated before and 1 and 4 days after surgery. Within this time interval epilation force was not significantly altered by the stress of surgery. *Am. J. Clin. Nutr.* 34: 2280–2286, 1981.

KEY WORDS Trichotillometry, nutritional assessment

Introduction

Although easily pluckable hair is a sign of known value in the diagnosis of protein-calorie malnutrition (1), there is little information concerning attempts to quantitate epilation force. The availability of a tool to estimate quantitatively and objectively the tension required to epilate individual hairs could provide a valuable, noninvasive method for the detection and assessment of protein-calorie malnutrition. Such an instrument was therefore designed and constructed and is herein referred to as a trichotillometer (Gr. tricho: hair; tillein: to pull; the instrument is still being perfected in its design and is not yet commercially available. The purposes of the present study were to determine if changes in epilation force, quantitated by use of the trichotillometer, could be correlated with established indicators of protein-calorie malnutrition of the marasmus and kwashiorkor types, and to determine if similar changes in hair pluckability are associated with acute stress such as surgery.

Materials and methods

Hair sampling technique

The trichotillometer is a hand-held spring dynamometer designed and constructed by one of the authors (CLK) specifically to measure the force in grams necessary to epilate individual hairs. The instrument consists of a calibrated metal ruler that slides out of a metal casing stretching a spring. The metal ruler is fitted at one end with a clip with which individual hairs are held as shown in **Figure 1**. A release mechanism is provided to immobilize the sliding ruler while clipping a hair. Pressing the release lever with the thumb, as shown in **Figure 2**, frees the sliding ruler that comes out stretching the spring as the operator pulls the casing away from the scalp, thereby exposing the calibrated scale. At the point of epilation the ruler locks in position by means of a ratchet, allowing the operator to read from the scale the tension required to detach the hair from the scalp. Each unit on the scale calibrates to 1.4 g throughout the range

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FIGS. 1 and 2. The trichotillometer in use.

of the instrument (from 0 to 62 g). Turning the instrument upside down releases the ratchet and allows the ruler to slide back into the casing.

Ten hairs from the vertex of each subject's scalp were epilated individually and the average of the 10 values recorded. The hairs were taped in a data collection book and later mounted on slides for microscopic examination. The percentage of broken hairs was recorded. Hair shaft diameter at a point immediately distal to the bulb was measured using a calibrated ocular micrometer, and the average for the unbroken hairs was taken.

Patient selection

A total of 37 hospitalized adult patients from the medical and surgical services of the University of Alabama in Birmingham Medical Center was studied. Seventeen patients with protein-calorie malnutrition were selected according to the following criteria: kwashiorkor, on the basis of serum albumin below 2.8 g/dl and total lymphocyte count below 1500 cells/mm^3; marasmus, on the basis of weight-for-height below 80% of standard, or the combination of triceps skinfold thickness less than 60% of standard and mid-arm muscle circumference less than 90% of standard. Sixteen patients who had no clinical or biochemical findings suggestive of malnutrition were taken as well-nourished controls. The majority of these were patients admitted for elective surgery. Four of the 37 patients could not be clearly categorized in either of the above groups because of the absence of the serum albumin level; nevertheless, all other parameters of nutritional status that were obtained in these four patients were included in the calculations of correlation coefficients with epilation force.

In order to evaluate the possibility that severe stress might acutely produce changes on epilation force, 18 patients undergoing elective surgery (14 well-nourished controls, two malnourished patients, and two with incomplete data) were evaluated by trichotillometry 1 day before surgery, and at 1 and 4 days after surgery. Surgical procedures included laparotomy, splenectomy, cholecystectomy, hemihepatectomy, nephrectomy, endarterectomy, hemicolectomy, radical mastectomy, hernia repair, hysterectomy, excision of a chest wall tumor, and abdominal perineal rectal resection. The protocol excluded all patients with any factor known to cause hair loss (i.e., antimetabolite therapy or irradiation).

Anthropometric and biochemical methods

Weight and height were obtained on each patient by direct measurement or from the hospital chart, and weight-for-height calculated as a percent of standard based on Metropolitan Life Insurance data (2). Triceps skinfold thickness was measured at the midpoint between the acromial process of the scapula and the olecranon process of the ulna using a Lange skinfold caliper. The mid-arm circumference was taken at the same point using a tape measure, and the mid-arm muscle circumference was calculated using the following equation: mid-arm muscle circumference (cm) = mid-arm circumference (cm) $-\ \pi$ (triceps skinfold thickness in cm). Percentage of standard for triceps skinfold thickness and mid-arm muscle circumference for age and sex was obtained using the standards of Frisancho (3).

Serum albumin, total lymphocyte count, and hematocrit were taken from the patient's chart. Serum β-carotene was determined by the method of Baker and Frank (4); vitamin A by the method of Garry et al. (5); folates were measured by microbiological assay as described by Herbert (6); vitamin B_{12} by radioisotope dilution assay with the procedure of Lau et al. (7) and ascorbic acid by the method of Zannoni et al. (8). Thiamin, riboflavin, and pyridoxine were assessed indirectly by determining the in vitro activation of erythrocyte

transketolase, glutathione reductase, and glutamic:oxaloacetic transaminase by the addition of appropriate cofactors as described by Bayoumi and Rosalki (9).

Results

Table 1 presents a comparison of the clinical and laboratory findings between the malnourished and the control (well-nourished) patients. The malnourished patients had values for weight, triceps skinfold thickness and arm muscle circumference that were significantly lower than those of the control group. Serum albumin was distinctly different between the two groups (2.9 ± 0.8 g/dl in the malnourished and 3.9 ± 0.6 g/dl in the control). With the exception of β-carotene, vitamin nutriture indicators were within normal limits in both groups.

Examination of the hair characteristics of the two groups revealed that the average force required to epilate hairs from the undernourished patients was significantly less (17.0 ± 11.8 g) than for the control patients (38.2 ± 11.4 g, $p < 0.001$) (Table 1). Hair shaft diameter was found to be only slightly smaller in the malnourished group (61.3 ± 11.4 versus 69.0 ± 10.5 μ $p < 0.10$). The percentage of hairs that broke upon epilation, a potentially confounding variable, was not greater among the malnourished patients.

Epilation force was correlated with age and each of the nutritonal parameters in the total patient sample. The results, shown in **Table 2**, revealed that epilation force correlated most significantly with serum albumin level ($r = 0.56$, $p < 0.001$) and hair shaft diameter ($r = 0.63$, $p < 0.001$). Plucking force correlated inversely with age ($r = -0.44$, $p < 0.01$). Because of this latter finding and because the average age of the malnourished group was somewhat higher (Table 1), hair plucking force was compared between the two study groups using covariance analysis. The results showed a significant group difference in epilation force, greater than could be accounted for by the group difference in age.

The correlation between epilation force and serum albumin is shown graphically in **Figure 3**. The malnourished patients are di-

TABLE 1
Comparison of clinical and laboratory parameters between the malnourished and control groups*

Parameter	Malnourished group	Control group	Level of Significance
n†	17	16	
Sex (no. males/no. females)	13/4	8/8	
Age (yr)	55 ± 18	45 ± 15	NS
Anthropometrics			
Weight (as % of ideal)	82 ± 23	116 ± 55	<0.05
Triceps skinfold thickness (% standard)	37 ± 14	113 ± 104	<0.02
Mid arm muscle circumference (% standard)	81 ± 14	103 ± 17	
Laboratory assessment			
Serum albumin (g/dl)	2.9 ± 0.8	3.9 ± 0.6	<0.001
Total lymphocyte count/mm^3	1409 ± 1256	1865 ± 545	NS
β-Carotene (mg/dl)	37.1 ± 31.9	76.2 ± 12.8	<0.001
Vitamin A (μg/dl)	21.9 ± 18.6	26.1 ± 12.8	NS
Thiamin (activity coefficient)	1.10 ± 0.15	1.10 ± 0.07	NS
Riboflavin (activity coefficient)	1.23 ± 0.21	1.26 ± 0.16	NS
Pyridoxine (activity coefficient)	1.21 ± 0.22	1.29 ± 0.30	NS
Folate (ng/ml)	6.6 ± 3.1	6.1 ± 2.4	NS
Vitamin B_{12} (pg/ml)	1287 ± 843	575 ± 289	<0.01
Ascorbic acid (mg/dl)	0.98 ± 0.62	0.50 ± 0.27	<0.05
Hair characteristics			
Epilation force (g)	17.0 ± 11.8	38.2 ± 11.4	<0.001
Shaft diameter (μ)	61.3 ± 11.4	69.0 ± 10.5	<0.10
Percentage broken	6.9 ± 10.1	11.3 ± 19.6	NS

* Data presented as mean ± SD.
† Not every parameter was available in each patient.

TABLE 2
Correlation of epilation force with other parameters of nutritional status

Parameter	(n)	Correlation Coefficient	Level of significance
Age	(37)	−0.44	<0.01
Anthropometrics			
Weight	(34)	0.36	<0.05
Triceps skinfold thickness	(35)	0.51	<0.01
Arm muscle circumference	(34)	0.43	<0.02
Laboratory assessment			
Serum albumin	(33)	0.56	<0.001
Total lymphocyte count	(30)	0.28	NS
Hematocrit	(33)	0.36	<0.05
β-Carotene	(23)	0.45	<0.05
Vitamin A	(23)	0.22	NS
Thiamin	(21)	0.10	NS
Riboflavin	(22)	0.27	NS
Pyridoxine	(23)	0.25	NS
Folate	(21)	−0.23	NS
Vitamin B_{12}	(23)	−0.28	NS
Ascorbic acid	(21)	−0.28	NS
Hair characteristics			
Shaft diameter	(34)	0.63	<0.001
Percentage broken	(35)	0.23	NS

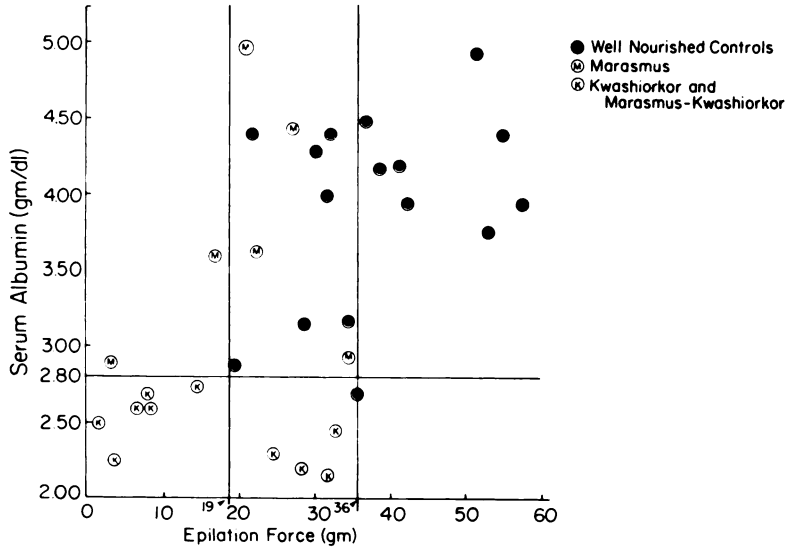

FIG. 3. Relationship between epilation force and serum albumin among patients with protein-calorie malnutrition and well-nourished patients.

vided into diagnostic categories of kwashiorkor and marasmus according to the criteria given in the "Materials and methods" section. At an epilation force of 19 g or less, only malnourished patients were identified, the majority of whom were categorized as having kwashiorkor. At forces greater than 36 g, only well-nourished patients were found. Average epilation force for each of the subgroups of malnutrition was compared with that of the well-nourished control group (see **Fig. 4**). Those patients with kwashiorkor, having or

not a component of marasmus, had markedly decreased epilation force compared to control patients (14.8 ± 12.3 versus 38.2 ± 11.4 g, $p < 0.001$). Patients with "pure" marasmus also had significantly decreased epilation force (20.9 ± 10.6 versus 38.2 ± 11.4 g for the controls, $p < 0.01$), but their hair tended to require a somewhat greater force than the patients with kwashiorkor or combined marasmus-kwashiorkor (20.9 ± 10.6 versus 14.8 ± 12.3 g, NS).

In order to assess the effect of acute stress on hair pluckability, epilation force was compared before and after elective surgery. As shown in **Table 3**, epilation force remained statistically unchanged from the day before surgery to one day and four days post surgery (38.4 ± 11.1, 38.6 ± 13.5, and 33.4 ± 10.1 g, respectively).

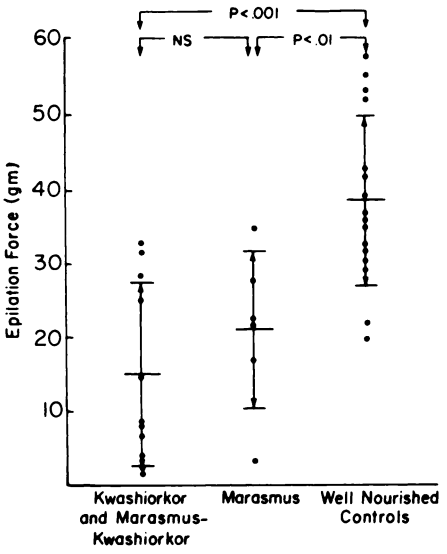

FIG. 4. Epilation force in patients with protein-calorie malnutrition and in well-nourished patients. Means and SDs denoted in each group.

TABLE 3
Comparison of epilation force (in g) before and after surgery*

1 Day before surgery (n = 18)	1 Day postsurgery (n = 18)	4 Days Postsurgery (n = 11)
38.4 ± 11.1	38.6 ± 13.5	33.4 ± 10.1
	NS	
	NS	

* Groups compared by paired *t* test, each patient serving as his own control.

Discussion

To the best of our knowledge prior reports related to the quantitation of hair plucking force are limited to a recent abstract by Kirby and Iber (10). These authors studied the force of epilation of individual hairs in a group of 100 alcoholics and compared it to that of 20 controls. The mean epilation force of their control group (37.5 ± 1.8 g) is very close to that of our control sample (38.2 ± 11.4 g). They found a slight but significant decrease in epilation force in their alcoholic patients (30.0 ± 2.0 g), some of whom presented with clinical evidence of mild protein-calorie malnutrition, primarily marasmus. In our study a malnourished population was selected on the basis of well validated indicators of protein-calorie malnutrition and included patients with marasmus, kwashiorkor, and combined marasmus-kwashiorkor. The epilation force data clearly demonstrated a pronounced drop among the malnourished patients. This abnormality seems related to changes in protein-calorie nutriture and not to vitamin status, as evidenced by the finding that epilation force correlated significantly with serum albumin level and anthropometric measurements, but not with the seven indicators of vitamin nutriture investigated. Some other interesting correlations emerged. The inverse correlation with age indicates that this factor needs to be taken into account when establishing normal values for epilation force. The positive correlation with β-carotene levels in plasma was an unexpected finding, but could well reflect inadequate food intake among the malnourished patients. The positive correlation of plucking force with hair shaft diameter is in keeping with the pioneering studies of Bradfield et al. (11) and of Sims (12) who found highly significant reductions in diameter in South American and African children affected by both forms of protein-calorie malnutrition. The positive correlation with hematocrit is not surprising and could possibly represent the simultaneous occurrence of two manifestations of protein-calorie malnutrition: anemia and decreased epilation force.

Hair breakage was considered a potential problem in our study. We found, however, that the number of hairs that broke before

epilation was small and that the percentage of broken hairs tended to be higher among the control patients (Table 1). This is to be expected since only a well-attached hair would require exerting a force high enough to break the shaft. It is important to point out that the error introduced by the artifact of breakage would result primarily in a lowering of the mean value obtained for the well-nourished group; elimination of this artifact would therefore enhance the difference observed between the malnourished and well-nourished subjects and strengthen the conclusions of the study.

Our attempt to assess the acute effects of severe stress on epilation force by repeating the assessment before and 1 and 4 days after surgery yielded results that must be cautiously interpreted. While it is clear that the stress of major surgery produced no change in epilation force 1 day after the operation, the data obtained 3 days later did suggest a drop in epilation force. The results, however, did not reach statistical significance. More prolonged and more numerous observations are required. In view of the studies of Bradfield and Margen (13) demonstrating morphological changes in the hair roots of protein-deprived volunteers at 11 days of depletion, it is conceivable that the combined insult of surgical trauma plus the decreased food intake and negative nitrogen balance of the postoperative period could precipitate structural changes that weaken the attachment of the hair to the scalp.

Although there is no information at present concerning the nature of the lesion responsible for the decreased epilation force in marasmus and kwashiorkor, Bradfield and coworkers (14, 15) have demonstrated a highly significant difference in the hair characteristics of marasmic and kwashiorkor patients. The former exhibit a striking shift to the resting phase of hair growth (telogen) with an almost complete lack of hair bulbs in the growing (anagen) phase. This telogen shift, interpreted by Bradfield (15) as an adaptive response to chronic undernutrition, has no time to occur in acute kwashiorkor where the normally preponderant anagen hairs suffer an abrupt interruption of their growing process. This difference is reflected in the morphology of the hair roots of marasmic and kwashiorkor patients which characteristically show loss of most of the external and internal sheaths in marasmus whereas hair pulled from kwashiorkor patients often comes out with intact sheaths. This supports the idea that the structures broken upon forceful epilation in marasmus and kwashiorkor are different. If so, a difference in the epilation force in kwashiorkor and marasmus could be observed and, indeed, our data suggest that the lowest epilation force values are likely to be found in kwashiorkor (Fig. 2). In a recent study on experimental protein-calorie malnutrition in pigs Bradfield and Pond (16) also noted that the hair of pigs with a kwashiorkor-like syndrome came out more easily than the hair of the marasmic-like pigs.

Bradfield (personal communication) believes that the transition between anagen and telogen can be upset in kwashiorkor in such a way that a nonuniform reduction in the structures of the hair follicle may occur. As a result he suggests the appearance of "mechanical misfits" which would allow the hair shaft to be easily extracted. Additionally, he postulates that intrafollicular edema, occurring concomitantly with edema in other parts of the body, may further weaken the attachment of hair in kwashiorkor.

It ought to be noted that hairs that have undergone a transition to the telogen phase remain in this phase approximately 90 days before they are shed and replaced by newly grown anagens. Thus, the marasmic patient with a "telogen shift" could have abnormal hair pluckability values months after his state of malnutrition had been corrected.

The range of epilation force of single hairs within an individual patient varied considerably. On the average the observed range among well-nourished patients, when plucking 10 individual hairs, was 36.0 ± 12.4 g. The values tended to distribute around the mean in a fashion slightly skewed toward the lower range, presumably reflecting the normal presence of a certain proportion of the more easily pluckable telogen hairs. Since the range of values within an individual is large, no conclusions ought to be drawn from the force required to pluck a single hair. Further studies will be needed to establish the *minimum* number of hairs that would have to be epilated to reliably distinguish a normal in-

dividual from one who is malnourished. Such studies may also clarify if, in fact, the range of values within an individual with marasmus tends to be greater compared to that of a patient with kwashiorkor.

In conclusion, our preliminary work indicates that trichotillometry can be used as an anthropometric indicator of protein-calorie nutriture. It may be of particular value in detecting the onset of a kwashiorkor state which is at present best assessed by laboratory assays and skin tests. By contrast, this method is simple, noninvasive, quantitative, and devoid of the risk of cross-infection. Furthermore, use of the trichotillometer requires essentially no prior training. Since the changes in epilation force must reflect changes at the hair root, trichotillometry data ought to become abnormal very early in the development of protein-calorie malnutrition, coinciding with or perhaps occurring before detectable changes in hair root morphology. Additional studies involving much larger groups are required to further validate the procedure and to better define the ranges of normal values as a function of age, sex, and race.

References

1. Jelliffe DB. The assessment of the nutritional status of the community. Geneva: WHO, 1966. (WHO Monograph. Ser. no. 53.)
2. Build and blood pressure study. Society of Actuaries. Chicago, 1959, Committee Report. Assessment of protein nutrition status. Am J Clin Nutr 1970;23: 807–19.
3. Frisancho AR. Triceps skinfold and upper arm muscle size norms for assessment of nutritional status. Am J Clin Nutr 1974;27:1052–7.
4. Baker H, Frank O. Vitamin A and carotenes. In: Clinical vitaminology. New York: Interscience, 1968.
5. Garry PS, Pollock JD, Owen GM. Plasma vitamin A assay by fluorometry and use of a silicic acid column technique. Clin Chem 1970;16:766–72.
6. Herbert V. Aseptic addition method for *Lactobacillus casei* assay of folate activity in human serum. J Clin Pathol 1966;19:12–6.
7. Lau K-S, Gottlieb C, Wasserman LR, Herbert V. Measurement of Serum vitamin B-12 level using radioisotope dilution and coated charcoal. Blood 1965;26:202–14.
8. Zannoni V, Lynch M, Goldstein S, Sato P. A rapid micromethod for the determination of ascorbic acid in plasma and tissues. Biochem Med 1974;11:41–8.
9. Bayoumi RA, Rosalki SB. Evaluation of methods of coenzyme activation of erythrocyte enzymes for detection of deficiency of vitamins B-1, B-2 and B-6. Clin Chem 1976;22:327–35.
10. Kirby SL, Iber FL. Decreased hair pulling pressure and impaired skin hypersensitivity—common abnormal nutritional parameters in alcoholics. Am J Clin Nutr 1980;33:937.
11. Bradfield RB, Poresky B, Cordano A. Hair diameter changes during protein-calorie malnutrition. Tokyo: Pacific Science Congress, 1966.
12. Sims RT. Hair growth in kwashiorkor. Arch Dis Child 1967;42:397–400.
13. Bradfield RB, Margen S. Morphological changes in human scalp hair roots during protein deprivation. Science 1967;157:438–9.
14. Bradfield RB, Cordano A, Graham, GG. Hair root adaptation to marasmus in Andean children. Lancet 1969;2:1395–7.
15. Bradfield RB: Effect of undernutrition upon hair growth. Hamburg, Germany: Proceedings of the First International Hair Research Conference, 1979.
16. Bradfield RB, Pond W. Hair copper during experimental protein-energy malnutrition in pigs. Am J Clin Nutr (in press).