Original Investigation

Relationship of Mediterranean Diet and Caloric Intake to Phenoconversion in Huntington Disease

Karen Marder, MD, MPH; Yian Gu, PhD; Shirley Eberly, MS; Caroline M. Tanner, MD, PhD; Nikolaos Scarmeas, MD, MS; David Oakes, PhD; Ira Shoulson, MD; for the Huntington Study Group PHAROS Investigators

IMPORTANCE Adherence to Mediterranean-type diet (MeDi) may delay onset of Alzheimer and Parkinson diseases. Whether adherence to MeDi affects time to phenoconversion in the Huntington disease (HD), a highly penetrant, single-gene disorder, is unknown.

OBJECTIVES To determine if MeDi modifies the time to clinical onset of HD (phenoconversion) in premanifest carriers participating in Prospective Huntington at Risk Observational Study (PHAROS), and to examine the effects of body mass index and caloric intake on time to phenoconversion.

DESIGN, SETTING, AND PARTICIPANTS A prospective cohort study of 41 Huntington study group sites in the United States and Canada involving 1001 participants enrolled in PHAROS between July 1999 and January 2004 who were followed up every 9 months until 2010. A total of 211 participants aged 26 to 57 years had an expanded CAG repeat length (≥37).

EXPOSURE A semiquantitative food frequency questionnaire was administered 33 months after baseline. We calculated daily gram intake for dairy, meat, fruit, vegetables, legumes, cereals, fish, monounsaturated and saturated fatty acids, and alcohol and constructed MeDi scores (0-9); higher scores indicate higher adherence. Demographics, medical history, body mass index, and Unified Huntington's Disease Rating Scale (UHDRS) score were collected.

MAIN OUTCOME AND MEASURE Cox proportional hazards regression models to determine the association of MeDi and phenoconversion.

RESULTS Age, sex, caloric intake, education status, and UHDRS motor scores did not differ among MeDi tertiles (0-3, 4-5, and 6-9). The highest body mass index was associated with the lowest adherence to MeDi. Thirty-one participants phenoconverted. In a model adjusted for age, CAG repeat length, and caloric intake, MeDi was not associated with phenoconversion (P for trend = 0.14 for tertile of MeDi, and P = .22 for continuous MeDi). When individual components of MeDi were analyzed, higher dairy consumption (hazard ratio, 2.36; 95% CI, 1.0-5.57; P = .05) and higher caloric intake (P = .04) were associated with risk of phenoconversion.

CONCLUSIONS AND RELEVANCE MeDi was not associated with phenoconversion; however, higher consumption of dairy products had a 2-fold increased risk and may be a surrogate for lower urate levels (associated with faster progression in manifest HD). Studies of diet and energy expenditure in premanifest HD may provide data for interventions to modify specific components of diet that may delay the onset of HD.

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Author Affiliations: Author affiliations are listed at the end of this article.

Group Information: The Huntington Study Group PHAROS (Prospective Huntington at Risk Observational Study) Investigators are listed at the end of the article.

Corresponding Author: Karen Marder, MD, MPH, 630 W 168th St, Unit 16, Columbia University College of Physicians and Surgeons, New York, NY 10032 (ksm1@cumc.columbia.edu).

CAG repeat length is the primary determinant of age of onset of Huntington disease (HD), but environmental modifiers of age of onset may also act. Converging evidence from murine and human HD point to a procatabolic state that may antedate overt motor manifestations of HD.[1-3] Numerous studies have demonstrated that individuals with manifest HD have lower body mass index (BMI; calculated as weight in kilograms divided by height in meters squared) than age-matched control subjects.[4-8] Weight loss is more prominent in humans and mice with greater CAG repeat length[9] and increases with disease progression.[4,6]

In a previous study,[10] the relationship between BMI, diet, and HD onset was examined by administering a semiquantitative food frequency questionnaire (FFQ)[11,12] to participants in the Prospective Huntington at Risk Observational Study (PHAROS),[13] who were at risk for HD but who had not undergone genetic testing at the time of enrollment. Because these participants did not know their genetic status, they were unlikely to have altered their diets differentially. We found no major differences in macronutrient consumption (protein, carbohydrates, and fat) between expanded and nonexpanded CAG repeat length groups.

Humans eat meals with complex combinations of nutrients or food items that are likely to be synergistic (or antagonistic), so that the action of the food matrix is different in each individual. One particular dietary pattern, Mediterranean-type diet (MeDi), has been widely explored in relation to various neurological disorders.[14,15] MeDi, a diet high in plant foods (eg, fruits, nuts, legumes, and cereals) and fish, with olive oil as the primary source of monounsaturated fat (MUFA) and low to moderate intake of wine, as well as low intake of red meat, poultry, and dairy products, is known to be beneficial for health owing to its protective effects in many chronic diseases.[16,17] Studies have found that higher adherence to MeDi may delay the onset of Alzheimer disease[14] and may be associated with older age at onset of Parkinson disease.[15] Nutritional supplements including coenzyme Q10, ethyl eicosapentaenoic acid, and creatine have been used in therapeutic trials in HD targeted at improving bioenergetics in manifest HD.[18] Double-blind, placebo-controlled trials of specific dietary interventions have not been conducted in premanifest HD. Our objectives in this prospective study are (1) to determine whether adherence to a MeDi affects time to diagnosis of HD (phenoconversion) among participants in PHAROS and (2) to examine the effects of BMI and caloric intake on time to phenoconversion.

Methods

Subjects

All the participants were enrolled in PHAROS between July 1999 and January 2004.[13] Institutional review boards at all participating sites approved the protocols and consent procedures. At baseline, participants were aged between 26 and 57 years and at risk for HD by virtue of having an affected parent or sibling. At the time of enrollment, participants had not undergone genetic testing for the CAGn expansion. Blinded genetic testing was performed at the baseline visit, and investigators and participants remained blinded to gene status for the duration of the trial. Details of the baseline assessment of these 1001 individuals and blinding procedures have been published.[13] At each assessment, an independent rater at each site performed the motor component of the Unified Huntington's Disease Rating Scale (UHDRS) and assigned a level of diagnostic confidence of HD based solely on the results of this motor examination. A rating of 4 indicated 99% or more confidence of clinically definite HD based on the presence of an unequivocal otherwise unexplained extrapyramidal movement disorder.[19] The first time a rating of 4 was given it was considered motor phenoconversion. Only participants who had an expanded CAG repeat length (≥37) and who did not have a diagnostic confidence rating of 4 at enrollment were included in these analyses. Subjects who phenoconverted at the visit when the FFQ was completed or for whom the visit was the last visit (n = 15) were excluded because we were interested in phenoconversion.

Dietary Assessment

Seven hundred thirty-eight individuals completed at least one National Cancer Institute FFQ, which has been shown to be reliable and valid.[12] The initial FFQ was administered, on average, 33 months after baseline examination. Details of the dietary assessment have been previously reported.[10] The analysis cohort includes 211 subjects with an expanded CAG repeat length. MeDi is defined by high consumption of plant foods, high intake of MUFA compared with saturated fatty acids (SFA), high intake of fish, low intake of meat (including poultry) and dairy products, and moderate consumption of alcohol (wine).

We followed the most commonly described method[16] to construct the MeDi score as described in previous reports[14,20,21] (http://onlinelibrary.wiley.com/doi/10.1002/ana.20854/full-bib31). More specifically, we first regressed total daily energy intake (measured in kilocalories) and calculated the derived residuals of daily gram intake[22] for each of the following 7 categories: dairy, meat, fruits, vegetables, legumes, cereals, and fish. Individuals were assigned a value of 1 for each component presumed to be beneficial (fruits, vegetables, legumes, cereals, and fish) if their caloric-adjusted consumption was at or above the sex-specific median, and for each detrimental component (meat and dairy products) if the caloric-adjusted consumption was below the sex-specific median. Individuals were assigned a value of 0 for each beneficial component if the caloric-adjusted consumption was below the sex-specific median, and for each detrimental, at or above the sex-specific median. For the fat component, we used the ratio of daily consumption (in grams) of MUFA to SFA, and a value of 1 was assigned if the intake was at or above the sex-specific median, and 0 if below the sex-specific median. Finally, subjects were assigned a score of 0 for either less than 4 g/d (approximately 1 glass of wine weekly) or more than moderate (≥30 g/d, approximately 1 glass of wine daily) consumption, and a value of 1 for mild to moderate alcohol consumption (>0 to <30 g/d). The MeDi score was generated for each participant by adding the scores in the food categories, with a higher score indicating better adherence to the MeDi. Thus, the MeDi score theo-

Table 1. Characteristics of 211 Participants With CAG≥37 at FFQ Completion Date by MeDi Tertiles

Variable	MeDi 0-3 (n = 67)[a]	MeDi 4-5 (n = 94)[a]	MeDi 6-9 (n = 50)[a]	*P* Value[b]
Age (range),y	44.1 (35.9, 48.6)	44.0 (37.9, 48.6)	42.8 (36.3, 51.2)	.66
CAG repeat length	42 (40, 43)	41.5 (40, 43)	42.5 (41, 44)	.048
Caloric intake	1847 (1376, 2176)	1764 (1414, 2306)	1785 (1480, 2597)	.68
BMI	27.1 (23.4, 31.6)	26.2 (23.6, 29.6)	25.8 (22.1, 28.8)	.03
UHDRS motor score	4 (1, 10)	3 (0, 8)	2 (1, 6)	.10
Chorea	0 (0, 3)	0 (0, 2)	0 (0, 2)	.59
Education status, y	14 (13, 16)	16 (12, 17)	16 (14, 17)	.09
Female sex	51 (76)	69 (73)	32 (64)	.16

Abbreviations: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); FFQ, frequency food questionnaire; MeDi, Mediterranean-type diet; UHDRS, Unified Huntington's Disease Rating Scale.

[a] Values shown are median (25th percentile, 75th percentile) or number (percent), as appropriate.

[b] *P* values shown are from trend tests from separate multiple regressions using ranks or from a Cochran-Armitage trend test, as appropriate.

Table 2. Adjusted Hazard Ratios (HRs) From Models to Predict Phenoconversion[a]

Variable	Full Model, HR (95% CI)	*P* Value	Small Model, HR (95% CI)	*P* Value
Age	1.14 (1.07-1.22)	<.001	1.17 (1.10-1.24)	<.001
Sex				
Male	1.0	.31		
Female	1.78 (0.58-5.42)			
CAG repeat length	1.46 (1.10-1.94)	.01	1.69 (1.32-2.17)	<.001
Caloric intake		.07[b]		.047[b]
Low	1.0		1.0	
Medium	0.61 (0.19-1.99)		0.97 (0.33-2.85)	
High	1.70 (0.65-4.43)		2.42 (0.99-5.92)	
BMI				
Low	1.0	.63[b]		
Medium	0.47 (0.16-1.36)			
High	1.41 (0.54-3.64)			
UHDRS motor score				
≤1	1.0	.08		
>1	3.42 (0.84-13.87)			
Chorea				
0	1.0	.42		
>0	1.51 (0.56-4.10)			
Education status	1.11 (0.94-1.30)	.21		
MeDi		.73[b]		.14[b]
0-3	1.0		1.0	
4-5	1.03 (0.41-2.57)		0.73 (0.32-1.71)	
6-9	0.74 (0.23-2.42)		0.44 (0.15-1.29)	

Abbreviations: BMI, body mass index (calculated as weight in kilograms divided by height in meters squared); MeDi, Mediterranean-type diet; UHDRS, Unified Huntington's Disease Rating Scale.

[a] Hazard ratios and *P* values shown are from Cox proportional hazards regression (full and small) models for time to phenoconversion.

[b] Trend test.

retically ranges from 0 to 9, with 0 indicating the least adherence to the MeDi and 9 the strictest adherence to the MeDi.

Statistical Analyses

The baseline was considered to be the visit at which the FFQ was completed, and the MeDi score from that visit was used as the main predictor in the analyses. The MeDi score was analyzed as a continuous variable and then as tertiles (0-3, 4-5, and 6-9). The association between demographic and clinical variables and adherence to the MeDi was compared among MeDi tertiles. Cox proportional hazards regression models were used to determine whether adherence to the MeDi modified time to phenoconversion, adjusting for demographic and clinical variables in a fully adjusted model and in a second, smaller model including only significant covariates. Covariates in the full model included the following measures at the time of completion of the FFQ: age, sex, BMI, caloric intake, education status, UHDRS motor score, and the chorea subscore of the UHDRS. Lastly, 9 individual components of the MeDi diet were included simultaneously in a model to predict phenoconversion, adjusting for age, CAG repeat length, and caloric intake.

Table 3. Association Between Individual MeDi Components and Phenoconversion[a]

Variable	Small Model, HR (95% CI)	*P* Value
Age	1.17 (1.10-1.25)	<.001
CAG repeat length	1.68 (1.29-2.19)	.001
Caloric intake		.04[b]
Low	1.0	
Medium	0.87 (0.28-2.75)	
High	2.69 (1.01-7.15)	
Cereal, low intake	1.12 (0.50-2.48)	.79
Dairy, high intake	2.36 (1.00-5.57)	.05
Fish, low intake	0.71 (0.29-1.75)	.46
Fruit, low intake	0.74 (0.30-1.82)	.51
Legumes, low intake	1.87 (0.75-4.62)	.18
Meat, high intake	0.86 (0.37-1.98)	.72
Vegetables, low intake	2.05 (0.74-5.72)	.17
MUFA/SFA, low intake	1.40 (0.61-3.19)	.43
Alcohol, moderate intake	0.81 (0.36-1.83)	.61

Abbreviations: MeDi, Mediterranean-type diet; MUFA, monounsaturated fat; SFA, saturated fatty acids.

[a] Hazard ratios and *P* values shown are from a single Cox proportional hazards regression model for time to phenoconversion.

[b] Trend test.

Results

Age, sex, caloric intake, education status, UHDRS motor score, and the chorea subscore did not differ among the MeDi tertiles (**Table 1**). The highest BMI was associated with the lowest adherence to MeDi (*P* = .02), before adjustment for covariates. Thirty-one of 211 subjects phenoconverted during the study period. Mean (SD) time to phenoconversion was 2.5 (1.7) years for phenoconverters compared with 4.3 (1.7) years of follow up for those who did not phenoconvert and were either followed up until the end of the study or lost to follow-up. Not surprisingly, phenoconverters were significantly older (47.9 [5.5] years compared with 42.6 [7.7] years) and had slightly higher CAG repeat length (42.4 [1.4] compared with 41.7 [2.0]) than subjects who did not phenoconvert during the study period. In a fully adjusted model (**Table 2**), age and CAG repeat length were associated with phenoconversion, but adherence to the MeDi was not. There was a trend for higher caloric intake, but not BMI, as a risk factor for phenoconversion. In a model including only significant covariates (age, CAG repeat length, and caloric intake), MeDi was not associated with phenoconversion (*P* = .14 and *P* = .22 for continuous MeDi), but higher caloric intake was marginally associated (*P* for trend = .047) (Table 2). When individual components of the MeDi were analyzed, only higher consumption of dairy products was associated with an increased risk of phenoconversion, hazard ratio 2.4 (95% CI, 1.0-5.57; *P* = .05 (**Table 3**); higher caloric intake was also associated with increased risk of phenoconversion in this model (*P* = .04).

Discussion

In some observational studies, adherence to the MeDi has been associated with reduced risk of certain neurological conditions and diseases including mild cognitive impairment,[23] Alzheimer disease,[14] cerebrovascular disease,[24,25] essential tremor,[26] and PD.[15] Potential mechanisms for some of these disease-modifying effects include an increased antioxidant effect[27] and reduced inflammation.[28] In this prospective study, we have shown that in individuals with an expanded CAG repeat length (CAG≥37), higher BMI is associated with lower adherence to the MeDi, and higher caloric intake was marginally associated with risk for phenoconversion.

Higher consumption of dairy products was associated with a 2-fold risk of phenoconversion after adjustment for age, caloric intake, and CAG repeat length, echoing a retrospective study of 51 families with HD in the Netherlands, in which higher milk consumption was associated with earlier onset of HD.[29] Numerous studies have shown an inverse relationship between consumption of dairy products and plasma uric acid, such that lower dairy consumption is associated with higher short- and long-term urate levels.[30] Higher urate levels have been associated with slower HD progression as measured by the total functional capacity scale during a 30-month period.[31] Urate levels have not been measured in premanifest HD (but have been measured in manifest HD). Prospective studies[32-34] have demonstrated an increased risk of PD for the highest quartiles of dairy intake that could not be attributed to calcium intake, particularly in men. Possible explanations for this association include the presence of low levels of pesticides in milk, or the fact that higher dairy consumption is related to lower circulating levels of urate and lower risk of gout. Dairy alone is dose-dependently linked to PD risk, and the dietary urate index, linked to PD risk, is driven by the dairy product-protein ratio.[35] In this study, high dairy consumption may be a surrogate marker for a low urate level. A high urate level may slow progression of established HD and PD and can lower the risk of PD. By extension, the 2-fold increased risk of phenoconversion associated with dairy consumption could be associated with reduced urate levels.

Dietary interventions in HD have been examined on a small scale. A hypercatabolic profile was identified in both early HD and premanifest HD, characterized by low levels of branched-chain amino acids. A trial of dietary triheptanoin to improve peripheral energy metabolism[18,36] using an anapleurotic approach was well tolerated, and a clinical trial is being planned. In a study of Wistar rats, extra virgin olive oil in conjunction with hydroxytyrosol was effective in reversing the effect of 3-nitropropionic acid on succinate dehydroxenase, suggesting that a component of the MeDi was effective in reducing lipid peroxidation in an HD-like model.[37]

Marder et al[10] have previously shown that higher total caloric intake, but not BMI, was associated with a 2-fold odds of carrying an expanded CAG repeat length (≥37) after adjustment for total motor score on the UHDRS in the PHAROS cohort. In the expanded CAG repeat length group, higher caloric intake, but not BMI, was correlated with higher CAG

(P = .03) and increased the 5-year estimated probability of HD[38,39] (P = .01). We concluded that increased caloric intake was necessary to maintain BMI in the premanifest state but could not determine whether this was due to a hypermetabolic state, subtle involuntary movements, swallowing impairment, or malabsorption. In this study, we show that higher caloric intake, and not BMI, was marginally associated with risk for actual rather than estimated phenoconversion.

Strengths of this study include the fact that participants did not know whether they carried an expanded CAG repeat length and, therefore, did not differentially modify their diets. Because they did not have HD at the time of administration of the FFQ, caloric intake or BMI were unlikely to be affected by extrapyramidal signs. All the participants were evaluated annually by movement disorders specialists who were also blind to genetic status. A validated FFQ and standard methods for caloric intake, MeDi calculation, and BMI measurements were used. The analyses were adjusted for several potential covariates. Limitations of the study include the administration of the diet survey at more than 30 months after study initiation, at which time there were individuals who had already developed HD or dropped out of the study, reducing our sample size and potentially introducing a survivorship bias.[10] Post hoc power calculations suggest that the study had 50% to 85% power to detect hazard ratios in the range of 2.0 to 3.0, so that some moderate-sized associations may have been undetected. Dietary assessments were self-reports, and there was no opportunity to validate dietary intake. We cannot determine whether presymptomatic HD carriers of an expanded CAG repeat length changed their dietary preference as they approached phenoconversion. Exploration of individual food groups was in the form of dichotomous variables, while continuous scores could have provided additional power. Blood was collected only for DNA, so urate, calcium, and other potential covariates could not be examined.

The fact that, in a highly penetrant single-gene disorder, there could be risk factors that modify disease onset is promising. Our results suggest that studies of diet and energy expenditure in premanifest HD may provide data for both nonpharmacological interventions and pharmacological interventions to modify specific components of diet that may delay the onset of HD.

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Author Affiliations: Departments of Neurology and Psychiatry, Columbia University College of Physicians and Surgeons, New York, New York (Marder, Scarmeas); Taub Institute for Research on Alzheimer's Disease and the Aging Brain, Columbia University, New York, New York (Gu); Gertrude H. Sergievsky Center, Columbia University Medical Center, New York, New York (Marder, Scarmeas); Department of Biostatistics and Computational Biology, University of Rochester, New York, New York (Eberly); Parkinson's Institute, Sunnyvale, California (Tanner, Oakes); Department of Social Medicine, Psychiatry, and Neurology, National and Kapodistrian University of Athens, Athens, Greece (Scarmeas); Department of Neurology, Georgetown University, Washington, DC (Shoulson).

Author Contributions: *Study concept and design:* Gu, Tanner, Scarmeas, Shoulson.
Acquisition of data: Marder.
Analysis and interpretation of data: Marder, Eberly, Tanner, Scarmeas, Oakes, Shoulson.
Drafting of the manuscript: Marder, Oakes.
Critical revision of the manuscript for important intellectual content: Gu, Eberly, Tanner, Scarmeas, Shoulson.
Statistical analysis: Gu, Eberly, Oakes.
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Group Information: The Huntington Study Group PHAROS Investigators are *Steering Committee*: Ira Shoulson, MD (principal investigator), Karl Kieburtz, MD, MPH (director, Clinical Trials Coordination Center), David Oakes (chief biostatistician), Elise Kayson, MS, RNC (project coordinator), Hongwei Zhao, ScD, M. Aileen Shinaman, JD (Huntington Study Group executive director), Megan Romer, MS, University of Rochester, Rochester, New York; Anne Young, MD, PhD (co-principal investigator), Steven Hersch, MD, PhD, Jack Penney, MD (deceased), Massachusetts General Hospital, Charlestown; Kevin Biglan, MD (medical monitor), The Johns Hopkins University, Baltimore, Maryland; Karen Marder, MD, MPH, Columbia University Medical Center, New York, New York; Jane Paulsen, PhD, University of Iowa, Iowa City; Kimberly Quaid, PhD, Indiana University School of Medicine, Indianapolis; Eric Siemers, MD, Lilly Corporate Center, Indianapolis, Indiana; Caroline Tanner, MD, The Parkinson's Institute, Sunnyvale, California. *Participating Investigators and Coordinators:* William Mallonee, MD, David Palmer, MD (deceased), Greg Suter, BA, Hereditary Neurological Disease Centre, Wichita, Kansas; Richard Dubinsky, MD, Gary Gronseth, MD, R. Neil Schimke, MD, Carolyn Gray, RN, University of Kansas Medical Center, Kansas City; Martha Nance, MD, Scott Bundlie, MD, Dawn Radtke, RN, Hennepin County Medical Center/Minneapolis, Minnesota; Sandra Kostyk, MD, PhD, George W. Paulson, MD, Karen Thomas, DO, Nonna Stepanov, MD, Corrine Baic, BS, Ohio State University, Columbus; James Caress, MD, Francis Walker, MD, Vicki Hunt, RN, Wake

Forest University School of Medicine, Winston-Salem, North Carolina; Sylvain Chouinard, MD, Guy Rouleau, MD, PhD, Hubert Poiffaut, RN, Brigitte Rioux (deceased), Hotel-Dieu Hospital-Centre hospitalier de l'universite de Montreal, Montreal, Quebec, Canada; Claudia Testa, MD, PhD, Timothy Greenamyre, MD, PhD, Joan Harrison, RN, Emory University School of Medicine, Atlanta, Georgia; Jody Corey-Bloom, MD, PhD, David Song, MD, Guerry Peavy, PhD, Jody Goldstein, BS, University of California, San Diego, LaJolla; Jane Paulsen, PhD, Henry Paulson, MD, Robert L. Rodnitzky, MD, Ania Mikos, BA, Becky Reese, BS, Laura Stierman, BS, Katie Williams, BA, Lynn Vining, RN, MSN, University of Iowa; Karen Marder, MD, MPH, Elan Louis, MD, MSc, Carol Moskowitz, RN, Columbia University Medical Center; Kimberly Quaid, PhD, Joanne Wojcieszek, MD, Melissa Wesson, MS, Indiana University School of Medicine; Ali Samii, MD, Thomas Bird, MD, Hillary Lipe, ARNP, University of Washington & VA Puget Sound Health Care System, Seattle; Norman Reynolds, MD, Karen Blindauer, MD, Jeannine Petit, ANP, Medical College of Wisconsin, Milwaukee; Peter Como, PhD, Frederick Marshall, MD, Timothy Counihan, MD, Kevin Biglan, MD, Carol Zimmerman, RN, University of Rochester; Penelope Hogarth, MD, John Nutt, MD, Pamela Andrews, BS, CCRC, Oregon Health & Science University, Portland; Steven Hersch, MD, PhD, Leslie Shinobu, MD, PhD, Diana Rosas, MD, Yoshio Kaneko, BA, Sona Gevorkian, MS, Paula Sexton, BA, CCRA, Massachusetts General Hospital; John Caviness, MD, Charles Adler, MD, PhD, Mayo Clinic Scottsdale, Scottsdale, Arizona; Vicki Wheelock, MD, David Richman, MD, Teresa Tempkin, RNC, MSN, University of California Davis, Sacramento; Chuang-Kuo Wu, MD, PhD, Hubert Fernandez, MD, Joseph H. Friedman, MD, Margaret Lannon, RN, MS, Brown University (Memorial Hospital of Rhode Island), Pawtucket; Lauren Seeberger, MD, Christopher O'Brien, MD, Sherrie Montellano, MA, Colorado Neurological Institute, Englewood; Ninith Kartha, MD, Sharin Sakurai, MD, PhD, Susan Hickenbottom, MD, PhD, Roger Albin, MD, PhD, Kristine Wernette, RN, MS, University of Michigan, Ann Arbor; Brad Racette, MD, Joel S. Perlmutter, MD, Laura Good, BA, Washington University, St Louis, Missouri; George Jackson, MD, PhD, Susan Perlman, MD, Shelley Segal, MD, Russell Carroll, MA, Laurie Carr, BS, UCLA Medical Center, Los Angeles, California; Wayne Martin, MD, Ted Roberts, MD, Marguerite Wieler, BSC, PT, University of Alberta, Edmonton, Alberta, Canada; Blair Leavitt, MD, Lorne Clarke, MD, CM, Lynn Raymond, MD, PhD, Joji Decolongon, MSC, Vesna Popovska, MD, Elisabeth Almqvist, RN, PhD, University of British Columbia, Vancouver, British Columbia, Canada; William Ondo, MD, Madhavi Thomas, MD, Tetsuo Ashizawa, MD, Joseph Jankovic, MD, Baylor College of Medicine, Houston, Texas; Robert Hauser, MD, Juan Sanchez-Ramos, MD, PhD, Karen Price, MA, Holly Delgado, RN, University of South Florida, Tampa; Sarah Furtado, MD, PhD, Anne Louise LaFontaine, MD, Oksana Suchowersky, MD, Mary Lou Klimek, RN, MA, University of Calgary, Calgary, Alberta, Canada; Rustom Sethna, MD, Mark Guttman, MD, Sandra Russell, BSW, RSW, Sheryl Elliott, RN, Centre for Addiction and Mental Health, Markham, Ontario, Canada; Marc Mentis, MB, CHB, Andrew Feigin, MD, Marie Cox, RN, BSN, Barbara Shannon, RN, North Shore University Hospital, Manhasset, New York; Alan Percy, MD, Leon Dure, MD, Donna Pendley, RN, Jane Lane, RN, BSN, University of Alabama at Birmingham; Madaline Harrison, MD, Elke Rost-Ruffner, RN, BSN, University of Virginia, Charlottesville; William Johnson, MD, University of Medicine and Dentistry of New Jersey Robert Wood Johnson Medical Center, Stratford; Amy Colcher, MD, Andrew Siderowf, MD, Mary Matthews, RN, University of Pennsylvania, Philadelphia; Danna Jennings, MD, Kenneth Marek, MD, Karen Caplan, MSW, Institute for Neurodegenerative Disorders, New Haven, Connecticut; Stewart Factor, DO, Donald Higgins, MD, Eric Molho, MD, Constance Nickerson, LPN, Sharon Evans, LPN, Diane Brown, RN (deceased), Albany Medical College, Albany, New York; Douglas Hobson, MD, Paul Shelton, MD, Shaun Hobson, RN, Winnipeg Clinic, Winnipeg, Manitoba, Canada; Carlos Singer, MD, Nestor Galvez-Jimenez, MD, William Koller, MD (deceased), Doris Martin, DDS, Kelly Lyons, PhD, Dinorah Rodriguez, RN, University of Miami, Miami, Florida; Kathleen Shannon, MD, Cynthia Comella, MD, Jean Jaglin, RN, CCRC, Rush Presbyterian–St Luke's Medical Center, Chicago, Illinois; Karen Anderson, MD, William Weiner, MD (deceased), Kelly Dustin, RN, BSN, University of Maryland School of Medicine; Adam Rosenblatt, MD, Christopher Ross, MD, PhD, Deborah Pollard, The Johns Hopkins University; Marie H. Saint-Hilaire, MD, Peter Novak, MD, J. Stephen Fink, MD, PhD (deceased), Bonnie Hersh, MD, Melissa Diggin, MS, RN, Leslie Vickers, RN, MS, Boston University, Botson; Wallace Deckel, PhD, James Duffy, MD, Mary Jane Fitzpatrick, APRN, University of Connecticut, Hartford. *Participating NIH Authors:* Elizabeth Thomson, PhD, National Human Genome Research Institute, Bethesda, Maryland; National Institute of Neurological Disorders and Stroke, Bethesda. *Event Monitoring Committee:* Steven Hersch, MD, PhD (cochair), Massachusetts General Hospital; Julie Stout, PhD (co-chair), James Calhoun, Indiana University; William Coryell, MD, Cheryl Erwin, JD, PhD, University of Iowa; Vicki Hunt, RN, Wake Forest University School of Medicine; Christopher Ross, MD, PhD, The Johns Hopkins University; Dorothy Vawter, PhD, Minnesota Center for Health Care Ethics. *Ethics Committee:* Lori Andrews, JD, Debbie Bury, James Calhoun, Chicago-Kent College of Law, Chicago, Illinois; Steven Hersch, MD, PhD (chair), Massachusetts General Hospital; Vicki Hunt, RN, Carl Leventhal, MD, Wake Forest University School of Medicine; Kimberly Quaid, PhD, Indiana University School of Medicine; Aileen Shinaman, JD, University of Rochester; Dorothy Vawter, PhD, Minnesota Center for Health Care Ethics; Nancy Wexler, PhD, Columbia University, New York. *Biostatistics and Clinical Trials Coordination Center:* Alicia Brocht, BA, Susan Daigneault, Karen Gerwitz, BS, Connie Orme, BA, Ruth Nobel, Victoria Ross, MA, Mary Slough, Arthur Watts, BS, Joe Weber, BS, Christine Weaver, Elaine Julian-Baros, University of Rochester. *Genetic/ Environmental Modifiers Committee:* Anne Young, MD, PhD (chair), Massachusetts General Hospital; Karen Marder, MD (co-chair), Columbia University Medical Center; Tatiana Foroud, PhD, Indiana University School of Medicine; James Gusella, PhD, Massachusetts General Hospital; David Housman, PhD, Massachusetts Institute of Technology, Boston; Marcy MacDonald, PhD, Massachusetts General Hospital; Richard Myers, PhD, Boston University; Caroline Tanner, MD, The Parkinson's Institute; Rudolph Tanzi, PhD, Massachusetts General Hospital. *Independent Monitoring Committee:* Stanley Fahn, MD, Columbia University; Michael Conneally, PhD (deceased), Indiana University; Weiu-Yann Tsai, PhD, Columbia University. *Scientific Advisory Committee:* Flint Beal, MD, New York Hospital Department of Neurology, New York; David Housman, PhD, Massachusetts Institute of Technology, Boston; Christopher Ross, MD, PhD, The Johns Hopkins University; Rudolph Tanzi, PhD, Anne Young, MD, PhD, Massachusetts General Hospital; Claudia Kawas, MD, University of California, Irvine; Marie Francoise-Chesselet, MD, PhD, University of California Los Angeles. *DNA Oversight Committee:* Michael Conneally, PhD (deceased), Indiana University Medical Center; Martha Nance, MD, University of Minnesota/ Minnesota VA Medical Center; Clifford Shults, MD (deceased), University of California, San Diego; Caroline Tanner, MD, The Parkinson's Institute. *Independent Rater Video Committee:* Penelope Hogarth, MD, Oregon Health & Science University; Diana Rosas, MD, Massachusetts General Hospital; Hongwei Zhao, ScD, University of Rochester.

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