Optimal Cutoff Values for High-Risk Waist Circumference in Older Adults Based on Related Health Outcomes

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The authors aimed to explore optimal cutoffs for high-risk waist circumference (WC) in older adults to assess the health risks of obesity. Prospective data from 4,996 measurements in 2,232 participants aged ≥70 years were collected during 5 triennial measurement cycles (1992/1993–2005/2006) of a population-based cohort study, the Longitudinal Aging Study Amsterdam (Amsterdam, the Netherlands). Cross-sectional associations of WC with pain, mobility limitations, incontinence, knee osteoarthritis, cardiovascular disease, and diabetes were studied. Generalized estimating equations models were fitted with restricted cubic spline functions in order to carefully study the shapes of the associations. Model fits for applying different cutoffs to categorize WC in the association with all outcomes were tested using the quasi-likelihood under the Independence Criterion (QIC). On the basis of the spline regression curves, potential WC cutoffs of approximately 109 cm in men and 98 cm in women were proposed. Based on the model fit, cutoffs between 100 cm and 106 cm were equally applicable in men but should not be higher. In women, the QIC confirmed an optimal cutoff of 99 cm.

Aging; cohort studies; overweight; risk assessment; waist circumference

Abbreviations: GEE, generalized estimating equations; QIC, quasi-likelihood under the Independence Criterion; WC, waist circumference.
functional outcomes and quality of life in gerontologic research. The independent associations of high WC with increased risks of diabetes (13), cardiovascular disease (14), mobility limitations (15–17), pain (18, 19), knee osteoarthritis (3), health-related quality of life (20), and urinary incontinence (in women) (21) among older adults have all been previously established. However, in order to identify cutoff values of WC that optimally classify the risk for these adverse outcomes in a population aged 70 years or older, the shapes of the associations between WC and these outcomes need to be carefully considered.

Our aim in this study was to explore optimal cutoff values for WC in older adults to assess the health risks of obesity. The shapes of the associations with several important health outcomes in gerontologic research were taken into account using advanced statistical methods.

**MATERIALS AND METHODS**

**Study sample**

Data for this study were collected within the Longitudinal Aging Study Amsterdam, a prospective study on predictors and consequences of changes in autonomy and well-being in the aging population in the Netherlands. A representative sample of older men and women (aged 55–85 years), stratified by age, sex, urbanicity, and expected 5-year mortality, was drawn from the population registers of 11 municipalities (rural and urban) in 3 geographic areas of the Netherlands. Details on the sampling and data collection procedures have been published elsewhere (22, 23). In total, 3,107 subjects were enrolled in the baseline examination (1992/1993). Examinations were repeated every 3 years and consisted of a main interview followed by a medical interview, both administered in the participant’s home. The examinations were conducted by specially trained and intensively supervised interviewers (main interview) and nurses (medical interview). Furthermore, a self-administered questionnaire was left at the participant’s home after the main interview and collected during the medical interview. The study was approved by the ethical review board of the VU University Medical Center (Amsterdam, the Netherlands), and all participants gave informed consent.

The sample used in the present study comprised participants who completed the medical examination in at least one of the 5 triennial measurement cycles between 1992/1993 and 2005/2006. For each cycle, participants aged 70 years or older at the time of the interview with complete data on WC were included. According to the World Health Organization, the currently used cutoff values are valid for persons under age 70 years (5). Our aim was to develop WC cutoff values for older adults aged 70 years or more in order to complement the World Health Organization guidelines. Of the 2,232 persons included in 1 or more measurement cycles, 860 participated in 1 measurement cycle only, 537 participated twice, 408 participated 3 times, and 297 participated 4 times; 130 participants had complete data from all 5 measurement cycles. In total, 4,996 measurements were available. Figure 1 shows the number of participants in each cycle.

**Measurements**

In the current study, the independent variable used was measured WC. The dependent variables studied were pain, self-reported mobility limitations, incontinence, and the chronic conditions cardiovascular disease, knee osteoarthritis, and diabetes. This broad range was considered to cover important issues pertaining to health-related quality of life in old age. In a final step of the analysis, we considered health-related quality of life as an overall summary outcome to test the validity of the potential cutoff values for WC.

**Waist circumference.** Anthropometric measurements were obtained by intensively trained nurses during the medical interview of each measurement cycle. WC (cm) was measured to the nearest 0.1 cm in the standing position, midway between the lower rib and the iliac crest, after a normal expiration.

**Pain.** During every measurement cycle, pain was assessed by means of a self-administered questionnaire. The pain scale used was based on a subscale of the Dutch version of the Nottingham Health Profile (24, 25). The 6 items included were the following: “I am in pain when I am standing”; “I find it painful to change position”; “I am in pain when I am sitting”; “I am in pain when I walk”; “I have unbearable pain”; and “I am in constant pain.” Response categories were “yes” and “no.” The pain score (range 1–6) was used as a dichotomous variable with the categories “no pain” and “any pain.”

**Mobility limitations.** Self-reported mobility limitations were assessed as part of the main interview in every measurement cycle, using the question, “Can you walk up and down a staircase of 15 steps without resting?” Response categories were “Yes, without difficulty,” “Yes, with some difficulty,” “Yes, with much difficulty,” “Only with help,” and “No, I cannot.” Participants were considered to be limited in their mobility when they answered “Yes, with much difficulty” or worse.

**Incontinence.** During the main interview of every measurement cycle, respondents were asked whether they (sometimes) lost urine unintentionally (yes/no).

**Chronic diseases.** The presence of chronic diseases was assessed by self-report in each measurement cycle. Participants were asked whether they had knee osteoarthritis and/or diabetes. The presence of cardiovascular disease was assessed by asking respondents whether or not they had cardiac disease (including myocardial infarction), stroke, and/or peripheral arterial disease. If respondents reported having at least 1 of these conditions, they were coded as having cardiovascular disease. It has previously been shown that the accuracy and reliability of self-reported chronic disease in the Longitudinal Aging Study Amsterdam is adequate (26).

**Health-related quality of life.** Participants completed the Dutch version of the 12-Item Short Form Health Survey (27) as part of the self-administered questionnaire during the third, fourth, and fifth measurement cycles for assessment of general mental and physical health. The 12-Item Short Form health scores were dichotomized for the analyses. Participants in the lowest sex-specific quartiles were considered to have a low health-related quality of life.
### Statistical analysis

In order to be able to use all data with adjustment for the dependence of observations within persons, we used generalized estimating equations (GEE) to examine the cross-sectional associations between WC and each of 7 health outcomes (i.e., pain, mobility limitations, incontinence, knee osteoarthritis, diabetes, cardiovascular disease, and health-related quality of life). Optimal WC cutoff values were determined using a 3-step approach.

First, restricted cubic spline regression functions with 4 knots were used to flexibly model the associations between WC and all 7 health outcomes, avoiding the need for an a priori assumption regarding the shape of the associations. Restricted cubic spline regression functions were chosen over unrestricted cubic splines in order to obtain more cautious estimates of the associations in the end regions of the distributions, where data are sparse. In order to identify cutoff values that optimally classify health risks for a heterogeneous population of older adults, we used univariate models (i.e., no adjustments for covariates were made). Three of the authors (N. H., M. B. S., and M. V.) independently assessed the most appropriate potential cutoff value by visual inspection of the spline regression curves of 6 outcomes. In order to validate our results, we assessed the association of WC with health-related quality of life at a later stage by testing the applicability of the identified cutoff value to classification of high risk for a general summary health outcome. A priori, there was consensus that an optimal cutoff value for WC should be set at the level where the risk for a particular health outcome starts to increase more rapidly. Because a stable change in health risks occurs in linear associations, this method was not applicable for linear associations. Using this method, 3 independent identifications of an optimal WC cutoff value for each particular health outcome were obtained, and the mean was calculated for each considered health outcome. Then an overall cutoff value for all health outcomes together was assessed by calculation of the mean, weighted by the prevalence of each of the outcomes in our study population. These potential WC cutoff values were further investigated in the next step.

In a second and more objective step, we applied a range of cutoff values for WC surrounding the potential cutoff values in order to dichotomize WC. The fit of the GEE models for the associations with all of the outcomes was investigated. The cutoff value that provided the best fit would be the optimal WC cutoff value to be proposed for older persons. Model fit was assessed using the quasi-likelihood under the Independence Criterion (QIC) (28); a lower QIC value indicates a better model fit.

In the third and final step, we used the curve of the association of WC with health-related quality of life to test the validity of the proposed cutoff value against an overall and summarizing outcome measure. In the literature, extensive evidence exists for a reverse relation between (co-)morbidity and health-related quality of life (29, 30). The model fit was assessed according to the above-described methods.

All analyses were performed separately for men and women in order to obtain potential sex-specific cutoff values for WC. The descriptive analyses were performed using SPSS 17.0 (31). The GEE spline regression analyses were carried out using R 2.7.0 (32); for assessment of the QIC values, SAS 9.2 (33) was used.

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**Figure 1.** Selection of a study sample comprising 2,232 participants aged ≥70 years in the Longitudinal Aging Study Amsterdam (Amsterdam, the Netherlands) and 4,996 waist circumference (WC) measurements carried out between 1992/1993 and 2005/2006.
Table 1. Characteristics of Participants Aged ≥70 Years in the Longitudinal Aging Study Amsterdam, Amsterdam, the Netherlands, 1992–2006

<table>
<thead>
<tr>
<th>Characteristic and Sex</th>
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<tr>
<td></td>
<td>Mean (SD) % No.</td>
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<tr>
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<td>77.7 (4.2) 52.2 51.9</td>
<td>78.5 (5.1) 45.6</td>
<td>78.9 (5.7) 45.6</td>
<td>78.4 (6.0) 45.0</td>
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<td>78.3 (5.3) 45.6</td>
<td>79.0 (5.8) 45.0</td>
<td>78.8 (6.0) 45.0</td>
<td>78.7 (6.0) 45.0</td>
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<tr>
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<td>100.2 (10.2) 472</td>
<td>101.6 (10.3) 391</td>
<td>101.7 (10.7) 347</td>
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<td>95.5 (11.9) 466</td>
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<tr>
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<td>30.2 371</td>
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<tr>
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<tr>
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<td>16.3 466</td>
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<tr>
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<tr>
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<td>11.4 562</td>
<td>9.3 474</td>
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<td>48.5 472</td>
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<tr>
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<tr>
<td>Male</td>
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<td>17.8 472</td>
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<tr>
<td>Female</td>
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<td>42.0 474</td>
<td>43.6 466</td>
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Abbreviation: SD, standard deviation.

RESULTS

The men and women in the study population had a mean age of approximately 78 years during all 5 measurement cycles. The youngest participants were aged 70.0 years in every measurement cycle, and the maximum age increased from 85.6 years to 96.6 years over the measurement cycles. The mean WC in men ranged from 99.2 cm to 101.7 cm over the measurement cycles, while the mean WC in women varied from 93.3 cm to 98.1 cm. The prevalences of the health outcomes studied are displayed in Table 1.

In the first step of the analyses, the spline regression curves showed an increased probability of all health outcomes with increasing WC in both men and women (Figure 2, Figure 3, and Figure 4). For the outcomes cardiovascular disease, diabetes, and knee osteoarthritis, there was a linear association with WC (Figure 2); therefore, no potential cutoff value could be determined by visual inspection. In contrast, the spline regression curves for pain, mobility limitations, and incontinence showed a nonlinear association. Therefore, we decided to use the curves for these 3 outcomes to propose the potential cutoff values in both men and women. In men, the curves for the associations of WC with pain and incontinence also showed increased probability in the lowest range of WC (U-shaped association). The lowest probabilities for these outcomes were found at 94.5 cm and 106.0 cm, respectively. On the basis of visual inspection, the potential WC cutoff values in men that seemed most appropriate in the associations with pain, mobility limitations, and incontinence were 104 cm, 111 cm, and 118 cm, respectively (Figure 3). In women, the potential cutoff values were 102 cm, 94 cm, and 95 cm for pain, mobility limitations, and incontinence, respectively (Figure 4). After calculating the weighted mean of the potential cutoff values according to the prevalence of each respective outcome, the potential cutoff values were 109 cm in men and 98 cm in women (Table 2).

In step 2, the fit of the models for all associations in men remained fairly stable when applying WC cutoff values between 100 cm and 106 cm (Figure 5, top). As compared with the currently used cutoff value of 102 cm, the models for cardiovascular disease and mobility limitations slightly improved, while the models for pain and knee osteoarthritis deteriorated. With the application of cutoff values higher than 106 cm and 108 cm, the improvement of the models stagnated, while the deterioration for other outcomes progressed. At higher cutoff values, the improvements in the models for cardiovascular disease and mobility limitations were clearly exceeded by the deterioration of the models for pain and knee osteoarthritis. Therefore, based on the QIC for the WC cutoff values in men, cutoff values in the range of 100–106 cm are equally applicable and cutoff values higher than 106 cm should not be applied. In women, the models for mobility limitations, pain, and incontinence improved when applying higher cutoff values than the currently used 88 cm. A break in the trend of progressive improvement in the model fit for mobility limitations and incontinence was evident when cutoff values higher than 99 cm were applied; additionally, the fit of the model for diabetes clearly deteriorated (Figure 5, bottom). Therefore, 99 cm seemed the most appropriate cutoff value for women based on the fit of the models.

In a final step, we tested whether the proposed cutoff values were valid in the association between WC and health-related quality of life, an overall summary outcome measure. Spline regression curves (Figure 6) and the model fit (Figure 5) were assessed for this association. In men, a U-shaped association was found. The lowest probability for a low health-related quality of life was found at a WC of 97.2 cm. On the basis of the spline regression curve, 106 cm seemed a more appropriate cutoff value for WC than 100 cm, because the risk was only marginally increased at a WC of 100 cm. The QIC measure for model fit remained stable when applying the range of cutoff values in the association with health-related quality of life in men. In women, the proposed cutoff value of 99 cm was appropriate in the association with health-related quality of life in terms of both the shape of the association (Figure 6) and the model fit (Figure 5, bottom) and was more optimal than the currently used cutoff value.

DISCUSSION

On the basis of this large-scale study relating WC to relevant health outcomes in older persons, we propose higher cutoff values for high-risk WC in older adults as compared with the cutoff values specified in current guidelines for adults (102 cm in men and 88 cm in women) (4, 5). In both men and women, the shapes of the associations between WC and pain, mobility limitations, and incontinence suggested higher cutoff values for WC. Analyses of model fit when applying a range of cutoff values to the association of WC with 7 health outcomes in men showed a stable fit when applying cutoff values in the range of 100–106 cm but indicated that cutoff values higher than 106 cm should be avoided. In women, the model fit analyses confirmed the results based on the shapes of the associations, and a cutoff of 99 cm was shown to optimally indicate a high-risk WC.

Although the World Health Organization guidelines clearly state that the cutoff values for WC are applicable to adults up to the age of 70 years (5), often these cutoff

![Figure 2. Spline regression curves for the associations of waist circumference with cardiovascular disease (—), knee osteoarthritis (· · · ·), and diabetes (– – –) among male (top) and female (bottom) participants in the Longitudinal Aging Study Amsterdam (Amsterdam, the Netherlands), 1992–2006.](image-url)
values are used to classify high-risk WC in older adults. Our study confirms that applying these cutoff values to persons aged 70 years or more leads to misclassification of health risks. Previous studies have considered the feasibility of the currently used cutoff values for WC in older adults based on their relation to other obesity measures, with inconsistent results. In 2 studies, investigators proposed lower cutoff values for older adults than those adopted in current guidelines, based on the amount of visceral fat and the ability to predict a high body mass index (7, 8). In contrast, in 3 studies (9–11), investigators proposed cutoff values higher than the current ones, based on the association between WC and body mass index in older adults. These previous studies all focused on how WC cutoff values relate to other anthropometric indices and their cutoff values. Changes in body composition and body fat distribution occur with aging (34, 35). At a given WC, the body mass index of an older adult is lower, while the amount of visceral fat and the waist-hip ratio is higher as compared with (younger) adults. No consensus has been reached in the scientific literature on optimal cutoff values for anthropometric indices like body mass index and waist-hip ratio in older adults (36). In the search for the optimal WC cutoff value with which to estimate obesity-related health risks in older adults, the

Figure 3. Spline regression curves for nonlinear associations between waist circumference and A) pain, B) mobility limitations, and C) incontinence among male participants in the Longitudinal Aging Study Amsterdam (Amsterdam, the Netherlands), 1992–2006. The arrows indicate the potential cutoff value based on visual inspection of each unique association, while the dashed lines indicate the currently used cutoff value (102 cm).
The association of WC with health outcomes is much more relevant, since this approach avoids the use of other obesity measures that may have limited validity in older persons or for which no generally accepted cutoff values exist.

An age-related redistribution of fat mass takes place in both older men and older women. In women, an accelerated shift toward a more central fat distribution takes place after menopause (37–40), while men already have a more centrally located fat distribution during adulthood as compared with women. This more pronounced redistribution of fat in women is a possible explanation for the finding that the cutoff value for high-risk WC needs to be shifted upwards in women but not in men.

To our knowledge, no previous study assessed WC cutoff values by considering the (shape of the) dose-response relation between WC and a wide range of health outcomes. In a previous study, we assessed the shape of the association between WC and mobility limitations as part of an examination of several methods for exploring cutoff values (11). In the current study, we applied the most optimal method, spline regression curves, to study a wide range of health outcomes that are very relevant to quality of life in older adults.
The spline regression curves for the outcomes cardiovascular disease, diabetes, and knee osteoarthritis in the current study showed gradual linear increases in health risk. Therefore, in these curves, a clear threshold for a high-risk WC was absent. In men, the curves of the associations of WC with some of the health outcomes also showed increased probability in the lowest range of WC (U-shaped associations). To test the robustness of the shape of the associations against confounding by the increased risk for several outcomes at the lowest end of the range of WC values, we performed additional analyses excluding participants with a low WC (<85 cm in men and ≤75 cm in women). The shapes of the remaining ranges of WC in association with the health outcomes remained virtually the same (results not shown).

The lowest probabilities for these negative outcomes (and thus the optimal WC) were found very close to or even above the currently used WC cutoff value (102 cm) for a high-risk WC in adult men. In women, an increased probability for a negative health outcome was not found, or was only marginally found, on the level of the currently used cutoff value (88 cm), with an exception for the association of WC with knee osteoarthritis. These results support the hypothesis that the currently used cutoff values are not applicable in older adults. When taking multiple important health outcomes into account, it is unlikely that a single cutoff value would be optimal for all health outcomes. However, for optimal clinical use and feasibility in daily practice, a single cutoff value for high-risk WC in older persons is to be preferred.

As compared with the model fit when applying the currently used cutoff value of 102 cm, the fit of the GEE models in men did not improve when we applied a range of cutoff values surrounding 102 cm. In women, the fit of the models for pain, mobility limitations, and incontinence improved, as we expected based on the shapes of the associations. Possibly, the fit of the models in men did not improve because the explained variance of the outcomes by WC is smaller than that in women, and the QIC might not be a sufficiently sensitive measure to detect improvement in the model by shifting the WC cutoff value.

Although data from 5 subsequent measurement cycles of the Longitudinal Aging Study Amsterdam covering 12 years of follow-up were available and were used, a limitation of the current study was its cross-sectional design. Therefore, reverse causation cannot be completely ruled out. However, performing longitudinal analyses was not possible. If associations of WC with the incidence of negative health outcomes were to have been considered, excluding all respondents with prevalent health problems at baseline would have made the sample size too small, resulting in curves estimated with less precision. By using the longitudinal data in a cross-sectional manner in GEE models, we were able to use all available data very efficiently, which led to increased statistical power and more accurate estimates of the shapes of the associations. A further limitation of the current study was the use of self-reported data on health outcomes; possible subclinical problems might have been missed by this assessment method.

Optimally differentiating low-risk groups from high-risk groups using more accurate cutoff values will prevent underestimation of the consequences of a high WC. The importance of maintaining a healthy weight throughout old age might be misjudged when health risks are underestimated in epidemiologic research. In addition, when the cutoff values used to select a target group for intervention better delineate those in need of intervention, the effects of an intervention can be correctly rated. The feasibility and efficacy of weight loss programs in older adults are still a subject of discussion in the scientific literature (41, 42).

As compared with the model fit when applying the currently used cutoff value of 102 cm, the fit of the GEE models in men did not improve when we applied a range of cutoff values surrounding 102 cm. In women, the fit of the models for pain, mobility limitations, and incontinence improved, as we expected based on the shapes of the associations. Possibly, the fit of the models in men did not improve because the explained variance of the outcomes by WC is smaller than that in women, and the QIC might not be a sufficiently sensitive measure to detect improvement in the model by shifting the WC cutoff value.

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**Table 2. Cutoff Values for High-Risk Waist Circumference in Persons Aged ≥70 Years Based on Visual Inspection of Spline Regression Curves of the Associations of Waist Circumference With Adverse Health Outcomes, as Assessed by 3 Study Investigators, Longitudinal Aging Study Amsterdam, Amsterdam, the Netherlands, 1992–2006**

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<th>Sex and Health Outcome</th>
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<th>Prevalence, %</th>
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<tr>
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<td>115</td>
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<tr>
<td>Women</td>
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<td>98</td>
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<tr>
<td>Mobility limitations</td>
<td>94</td>
<td>95</td>
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</tr>
<tr>
<td>Incontinence</td>
<td>95</td>
<td>94</td>
<td>94.5</td>
</tr>
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</table>

* The mean of the 3 observed cutoff values for each outcome was weighted by the prevalence of the outcomes to calculate the potential cutoff values.
values for WC should be shifted upwards in older adults. When assessing the quality of the models, shifting the cutoff values upwards did not improve the model fit in men. Cutoff values between 100 cm and 106 cm were shown to perform comparably, but higher cutoff values should be avoided. In women, the data suggested an optimal cutoff value of 99 cm, both considering the shapes of the associations with important health outcomes and in terms of model fit. In future research, these proposed cutoff values should be validated in other, large (inter-)national samples before the final cutoff values can be established and applied in clinical practice.

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