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Development of a clinical risk score in predicting undiagnosed diabetes in urban Asian Indian adults: a population-based study

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Summary
Objectives: India has the largest burden of diabetes in the world, much of which remains undiagnosed. This study aimed to develop a risk score to predict the likelihood of having undetected diabetes in individuals, based on identification of non-invasive risk factors for Type 2 diabetes.
Methodology: The risk score was developed in urban and rural participants, aged 35—64 years, from a representative cross-sectional population survey conducted in Delhi in 1991—1994. Multivariable logistic regression model coefficients were used to assign each categorical risk factor a score value with undiagnosed diabetes as the dependent variable. The validity of the composite risk score was tested in an independent multicentre cross-sectional survey conducted in 2001—2003 in a different population.
Results: Complete baseline data were available for 4044 men and women in the first population, of whom, 440 had diabetes (199 cases undiagnosed). Age, waist circumference, blood pressure and family history of diabetes were significant ($p < 0.01$) non-invasive predictors of diabetes status in the multivariable model. The risk of having diabetes increased progressively as the risk score rose from 0 to 29. When tested in the independent population ($n = 10566$, of whom 1066 had diabetes and 375 were undiagnosed), a score value >16 predicted diabetes status with a sensitivity of 0.79 (95% CI:0.77—0.82), specificity of 0.56 (95% CI:0.55—0.57), and a positive likelihood ratio of 1.8 (95% CI:1.7—1.9) for all cases with diabetes, and a sensitivity

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of 73%, specificity of 56% and a positive likelihood ratio of 1.6 (95% CI: 1.5—1.7) for undiagnosed diabetes cases.
Conclusion: Application of this risk score identified a substantial proportion of individuals with undiagnosed diabetes, using tools easily available in low-resource settings.

Introduction

India has the largest number of persons with diabetes among all countries and will triple its burden between 1995 and 2025 [1]. This will be characterized by a rapid increase in the prevalence of diabetes, especially in urban areas, and widening urban—rural gaps in diabetes related disease burdens. This is already evident in many parts of India [2,3], and has important implications for the future burden of cardiovascular disease (CVD), as Type 2 diabetes is a major risk factor for vascular disease and death.

Much of this burden is undiagnosed; a half to two-thirds of individuals with hyperglycemia are undiagnosed [4—6] in India due to lack of awareness, lack of resources, and a healthcare infrastructure which is not geared to deal with chronic diseases. While identification of individuals with undiagnosed hyperglycemia is essential, mass screening for its detection cannot be recommended because it would be invasive, costly and unsustainable. As Type 2 diabetes is associated with many clinical risk factors, identification of individuals having a clinical profile, which is associated with a high probability of Type 2 diabetes is likely to be a cost-effective alternative [7]. Only individuals with a high probability of Type 2 diabetes will then require undergoing targeted blood testing. Such a strategy has additional advantages, in that the presence of many of these risk factors increases the risk for CVD as well, hence their detection will provide an opportunity for targeted primary prevention.

We developed a clinical risk score, based on a combination of several non-invasive risk factors easily measured at a primary healthcare level, to estimate the likelihood of an individual having hyperglycemia. The aim of our study was to develop a simple and practical model for primary healthcare providers to identify individuals likely to be at a high risk of having Type 2 diabetes, and to validate the model in an independent population.

While such risk scores have been developed extensively in western countries, predominantly for the Caucasian population, risk prediction rules are few and recent in South Asian countries, where Type 2 prevalence of diabetes is high [4].

Methods

For development of the risk score, we used data from a study (ICMR Task Force Project on Collaborative Study of Coronary Heart Disease — Delhi Center), conducted by three of the investigators (KSR, PS, BS) on behalf of the Indian Council of Medical Research, in urban and rural North India (urban Delhi and rural Haryana, respectively) in 1991—1994, henceforth referred to as Population A. The sampling methodology has been described elsewhere [8]. Briefly, the design was that of a cross-sectional study and sampling methodology involved stratification of geographical zone and type of residential locality followed by multi-stage random cluster sampling in each stratum in the urban areas. In rural areas random stratified sampling was done based on the village size. All individuals of both sexes, aged 35—64 years were eligible to participate. The response rate was 94% for the urban component and 50% for the rural areas for the biochemical component of the study. After obtaining consent, 5537 individuals (52.2% women) were surveyed by questionnaire, clinical examination, blood sampling and an electrocardiogram for presence of vascular disease and its risk factors. The profile of respondents and non-respondents for blood sampling was similar for age, sex, locality and socio-economic status in the rural areas. The interviewer administered questionnaire was designed to elicit information regarding demographic variables, risk behaviours, past and current medical history, and family history as relevant to the study of CVD risk. Clinical examination included: measurement of seated blood pressure, prior to blood sampling, using standard methodology [9], by a regularly calibrated random zero sphygmomanometer with an average of two readings, taken 5 min apart; weight was measured to the nearest kilogram, using a single bathroom scale, which was calibrated on a daily basis with known weights; height, measured using a stadiometer, to the nearest centimeter; waist circumference, measured to the nearest 5 mm in the mid-axillary line at the center of two points defined by the subcostal margin and the highest point of the iliac crest. Measurements were done with a fibre glass tape after

applying a tension of 600 g (with the help of a spring balance). All the measurements were taken without intervening clothes.

Blood samples were collected in a fasting state for plasma glucose and lipids including total cholesterol, high-density lipoprotein cholesterol (HDL), and triglyceride. Blood glucose measurements were performed in the plasma by the enzymatic colorimetric GOD-PAP method using Boheringer–Mannheim kits; cholesterol by the CHOD-PAP method; triglycerides by GPOD-PAP method, and HDL by the precipitation method (Phosphotungstate/Mg). The laboratory underwent regular internal as well as external quality control measures.

For validation of the model, we used data from a multi-centre cross-sectional baseline survey of adults (20–69 years) in an industrial setting, which is part of an ongoing project on surveillance of cardiovascular disease in Indian industrial populations, henceforth referred to as Population B. The details of this population and survey methodology are described elsewhere [10]. The baseline survey of risk factors and determinants of CVD was carried out, after informed consent, during 2001–2003. The study was conducted using study instruments and methods exactly similar to those described above, except for blood pressure which was measured in this study by an automated blood pressure measuring device (Omron MX3, Omron Corporation, Japan) calibrated regularly as per the requirements. Blood pressure was taken with standard precautions [11] before blood sampling. The response rate for the survey was 89.7% and the profile of respondents and non-respondents was similar [10].

Definitions of variables

Presence of diabetes was defined as fasting plasma glucose value of 126 mg/dl ($\geqslant$7.0 mmol/l) or a medical history of receiving treatment for diabetes. Undiagnosed diabetes was defined as those who had fasting blood glucose 126 mg/dl ($\geqslant$7.0 mmol/l) but were not aware of their glycemic status. Therefore total diabetes in the population comprised of those with known diabetes and presence of fasting hyperglycemia in those with no history of diabetes. Only fasting glucose criteria were used to define diabetes. Classification of blood pressure by the 7th Joint National Committee (optimal blood pressure, pre-hypertension, and hypertension) was used to estimate risks associated with blood pressure [12]. Abdominal obesity was defined using waist circumference thresholds that are lower than reported in the western literature, as it has been shown that the risk of developing diabetes increases much before the anthropometric cut-offs proposed for the Caucasian populations [13,14–16]. We employed waist circumference cut-offs of 75 cm and 85 cm in women, and >80 cm and 90 cm in men as risk thresholds for diabetes. Risks associated with age were defined using categories of age <40 years, 40–49 years, and $\geqslant$50 years.

Statistical analysis

Initially, logistic regression was used to compute uni-variate and multi-variable b coefficients and odds-ratios for known risk factors of diabetes, with undiagnosed diabetes as the dependent variable. These were age, sex, body-mass index, waist circumference, blood pressure, family history of diabetes, current smoking, educational status, high total/HDL cholesterol ratio and hypertriglyceridemia. Subsequently risk factors that were not significant predictors at $p = 0.10$ or added little value to the model were removed. We did not include any interaction terms or biochemical variables as such high total/HDL cholesterol ratio and hypertriglyceridemia, which were significant predictors of presence of diabetes in the multi-variable model, to keep the risk score simple and practical. A score was assigned to each selected variable, based on significance at $p < 0.05$ in the multi-variable analysis, by multiplying its ß-coefficient in the regression model by 10 and rounding off to the nearest integer, while the reference category of the variable was assigned a value of 0. A composite risk score was then calculated as a sum of individual scores. The overall usefulness of the composite risk score was tested using Receiver Operator Characteristic (ROC) curves, which were generated by plotting sensitivity and 1-specificity for each score value, and estimating the area under the curve (AUC) with 95% confidence intervals (CI) for each ROC. The larger the area under the curve, the better the performance of the screening test. The individual scores for risk variables derived from Population A were applied in a similar fashion for validation to Population B for all individuals with diabetes and those with undiagnosed diabetes, separately. Subsequently, optimal thresholds of the combined risk score were determined and statistics of sensitivity, specificity, and positive and negative predictive values and likelihood ratios were generated, for the selected thresholds with the help of a clinical calculator [17]. Logistic regression analyses and all other statistical analyses were conducted using SPSS version 9.0 (SPSS Inc., Illinois, USA).

Results

The characteristics of Populations A and B are described in Table 1. Of the 5537 individuals surveyed in Population A, complete information relevant to this study was available for 4044 individuals. Of these, 440 respondents had diabetes, 241 with history and the rest by fasting plasma glucose status. Complete information relevant to this study was available for 10566 individuals in population B. The male preponderance (70%) in this population represented the largely male employee profile of these industries. Of these, 1066 had diabetes, 691 by history and the rest by fasting plasma glucose status.

The overall prevalence of diabetes was 10.9% in the 1991–1994 population (Population A) and 10.1% in the 2001–2003 population (Population B). The prevalence of undiagnosed diabetes was 4.1% and 3.6%, respectively. There were differ-

Table 1 Characteristics of Populations A (1991–1994) (model development) and Population B (2001–2003) (model validation)

	Population A (n = 4044)		Population B (n = 10566)	
Age range (years)	35–64		20–69	
% of women	52		37	
	Men	Women	Men	Women
Age				
Mean age (yrs)	47 (9)	46(9)	42 (11)	39 (11)
% <40 years	25	28	36	49
% 40–49 years	35	34	35	35
% ⩾50 years	40	38	29	16
Mean body-mass index (kg/m^2)	22.7(4)	23.9 (5)	23.5 (4)	24.3 (5)
Abdominal obesity				
Mean waist circumference (cm)	85 (13)	77 (13)	87 (10)	81 (12)
% in waist category I	39	44	25	33
% in waist category II	27	29	38	30
% in waist category III	34	27	37	37
Blood pressure				
Mean systolic blood pressure (mmHg)	120 (19)	119 (21)	127 (16)	122 (18)
% with pre-hypertension	31	24	41	33
% with hypertension	22	24	31	26
Glycemic status				
Mean fasting plasma glucose (mg/dl)	97	96	96	93
Diabetes (%)*	11.1	10.7	11.2	8.1
Known diabetes (%)	6.1	5.8	7.5	5.0
Family history of diabetes	13	11	16	18
Hypertriglyceridemia[13] (%)	42	37	32	20
High TC:HDL ratio ⩾ 4.5[31] (%)	58	45	43	22
Educational status				
1: Professional/post-graduate/graduate (%)	33	18	39	38
2: Secondary level (%)	44	29	50	36
3: Less than secondary level (%)	23	53	11	26
Current smoking (%)	34	8	23.5	0.2

Waist categories defined as follows

Waist (cm)	Women	Men
I	⩽75	⩽80
II	75–85	80–90
III	>85	>90

Continuous variables summarized as mean (SD).
[a]Diabetes defined as fasting plasma glucose of ⩾126 mg/dl (7 mmol/l) or a history of being treated for diabetes.

ences in the baseline characteristics of individuals with known and undiagnosed diabetes in Population B in terms of age, fasting plasma glucose and family history of diabetes (Table 2).

The multi-variable odds, with undiagnosed diabetes as the dependent variable in the final regression model, and assigned score values of selected variables are given in Table 3. Age $\geqslant$40 years, presence of elevated blood pressure, family history of diabetes in parents or siblings, and increased waist circumference (>75 cm in women and >80 cm in men) were significant predictors of diabetes status in the model. Sex, current smoking status, and educational status were not significant predictors of diabetes status. In terms of the proportional attributability, waist circumference had the largest wald statistic among different variables. BMI added little to the model predictability (Nagelkerke R^2 value changing from 0.088 to 0.089) and showed a high correlation with waist circumference (Pearson correlation coefficient 0.7, $p < 0.001$). Hence it was not included in the final model.

A composite risk score was calculated as described in the methodology section. The score ranged from 0 to 29. The mean ± SD of the composite risk score was 12.9 ± 7.8 for cases with undiagnosed diabetes in population A and 14.9 ± 7.7 for all cases with diabetes and 14.5 ± 7.6 for cases with undiagnosed diabetes in Population B. The area under the curve (AUC) was significant ($p < 0.001$ for all) in both the populations for prediction of diabetes; AUC 0.72 (95% CI: 0.68—0.75) for undiagnosed cases in Population A and 0.74 (95% CI: 0.73—0.76) and 0.69 (95% CI: 0.66—0.71) for all cases and undiagnosed cases in Population B, respectively. (Figs. 1 and 2).

The composite risk score in both populations was classified into four risk score categories of 0—9, 10—16, 17—25, and 26—29. The prevalence of diabetes increased with increasing risk score value in both populations (chi-square for linear trend, $p < 0.001$ in both populations) as shown in Fig. 3. Individuals with a score of 0 (none of the risk variables present) had a very low prevalence of diabetes (1.3% in Population A for undiagnosed diabetes, and 0.8% in Population B for both total and undiagnosed diabetes).

Sensitivity, specificity, positive and negative predictive values and likelihood ratios which predict presence of diabetes, at a threshold of the composite risk score >16, are shown in Table 4. A score of >16 identified 66% individuals with undiagnosed hyperglycemia with a specificity of 67% in Population A, and 79% and 73% individuals with

Table 2 Characteristics of individuals with diagnosed and undiagnosed diabetes in the study populations

Variable	Population A (1991—1994)		Population B (2001—2003)	
	Known diabetes	Undiagnosed diabetes	Known diabetes	Undiagnosed diabetes
Number (n)	241	199	691	375
% women	51	52	28	33
Mean age ± SD (yrs)	52 ± 8	49 ± 9*	50 ± 7	47 ± 9*
Mean ± SD body-mass index (kg/m^2)	26.3 4.9	26.6 ± 5.2	25.5 ± 4	25.4 ± 4
Mean ± SD fasting plasma glucose (mg/dl)	159 ± 68	163 ± 52	142 ± 56	165 ± 48*
Mean ± SD waist circumference (cm) in men	93 ± 11	92 ± 11.4	91.4 ± 8.4	91 ± 10.4
Mean ± SD waist circumference (cm) in women	85.5 ± 12	84.7 ± 13	88.5 ± 11.5	88.2 ± 10.4
Age $\geqslant$ 40 years (%)	93	84*	94	80*
Family history of diabetes	40	18*	35	16*
Pre-hypertension (%)	29	33	31	34
Hypertension (%)	50	38	54	48
Waist category II (%)	28	32	36	33
Waist category III (%)	56	52	56	55
Total cholesterol: HDL/ cholesterol ratio $\geqslant$ 4.5[31] (%)	64	70	51	47
Hypertriglyceridemia[13] (%)	55	61	48	42
Education				
Till primary (%)	24	36	19	15
Till secondary (%)	42	37	51	56
Graduate (%)	33	27	30	29

* Significant difference between known and undetected cases, $p < 0.05$.

Table 3 Multi-variate odds of having diabetes according to risk factor status in Population A (1991–1994)

Variable	Univariate regression		Multiple logistic regression				
	Odds ratio	P	ß-Coefficient	ORs	p	Wald	Score (ß × 10)
Age							
<40 years	1						0
40–49 years	1.7	<0.05	0.4	1.4	0.1	2.7	4
>49 years	2.3	<0.001	0.6	1.8.	<0.01	6.9	6
Blood pressure							
Optimal blood pressure	1			1			0
Pre-hypertension	2.2	<0.001	0.5	1.7	<0.01	7.5	5
Hypertension	3.5	<0.001	0.7	2.1	<0.001	13.9	7
Waist circumference							
⩽75 cm in women and ⩽80 cm in men	1			1			0
>75 cm in women and 80 cm in men	3.2	<0.001	0.9	2.4	<0.001	12.8	9
>85 cm in women and 90 cm in men	5.3	<0.001	1.2	3.2	<0.001	18.6	12
Family history of diabetes							
Absent	1			1			0
Present	2.0	<0.001	0.4	1.5	<0.05	4.1	4
BMI (kg/m²)							–
<23	1						
⩾23	3.1	<0.001					
Current smoking status in males							–
Non-smokers	1						
Smokers	0.8	0.11					
Education							–
Graduates or more	1						
Less than graduate and more than primary	1.0	0.8					
Upto primary	1.0	0.4					

total and undiagnosed hyperglycemia, respectively, in Population B with 56% specificity. There were no significant sex-wise differences in the performance of the risk score, in either of the two populations. Fig. 4 shows the sex-wise sensitivity and specificity of a risk score >16 in predicting undiagnosed diabetes in Populations A and B. Individuals with a risk score >16 who did not have hyperglycemia, still had an adverse cardiovascular and metabolic risk profile (Table 5).

Discussion

Increasing urbanization, adoption of adverse lifestyles and possibly enhanced genetic susceptibility are contributing to a rising prevalence of Type 2 diabetes mellitus in India [18]. India has the largest absolute burden of diabetes in the world and it is projected that by 2025, the number of people with diabetes in India will rise to more than 57 million [1]. Most of this rise will be due to increases in Type 2 diabetes, for which awareness in the Indian population is still low.

The composite risk score evolved from this study reasonably predicts the likelihood of having undetected diabetes using simple measures of risk benefits. Two-thirds to three-fourths of individuals with hyperglycemia could be identified by this risk score with reasonable specificity with a cut-off of risk score >16. However the choice of threshold involves a trade-off between sensitivity and specificity and will need to be based on the resources available to the healthcare system. Individuals with a risk score 0–9 have a low probability of having undiagnosed diabetes and need not be investigated further. At the same time the score value can be used, in such persons, to emphasize maintenance of low-risk status through healthy lifestyle practices. In practical terms, adults less than 40 years of age will need to be further evaluated only if they have multiple other risk factors. The threshold for screening individuals aged >40 years will be much lower, with the presence of either multiple risk

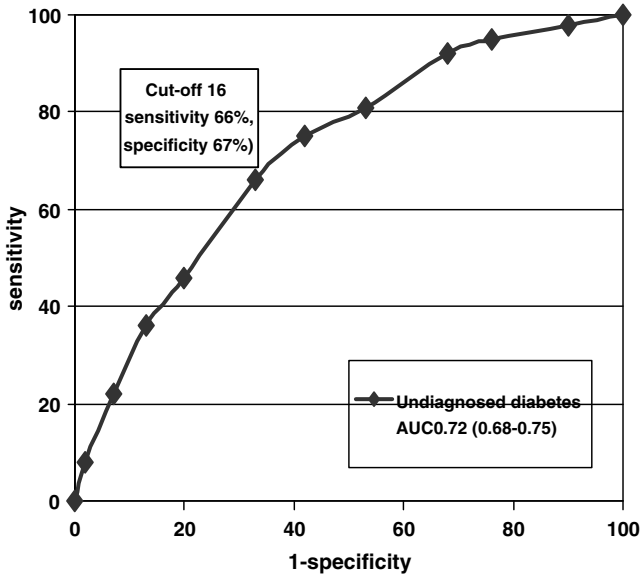

Figure 1 ROC curves showing the performance of the risk score in predicting undiagnosed diabetes in Population A (1991—1994). Area under the Curve for undiagnosed diabetes was 0.71 (95% CI: 0.63—0.71, $p < 0.001$).

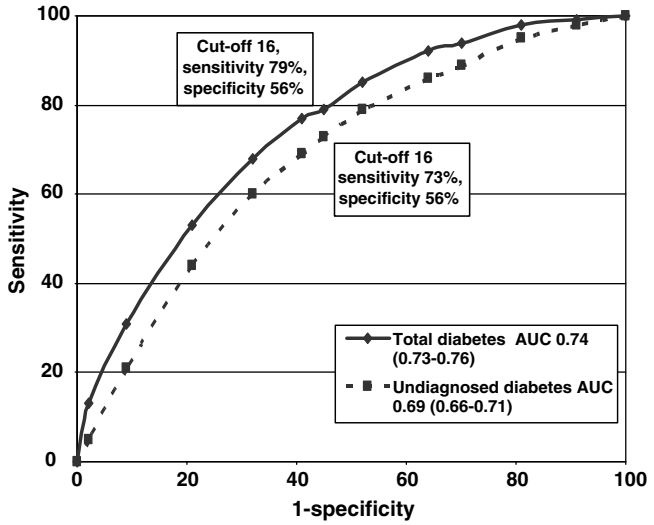

Figure 2 ROC Curves showing the performance of the risk score in predicting total and undiagnosed diabetes in Population B (2001—2003). Area under the curve for total diabetes was 0.73 (95% CI: 0.70—0.75, $p < 0.001$) and for undiagnosed diabetes was 0.68 (95% CI: 0.61—0.70, $p < 0.001$).

factors to a lower extent, or extreme deviations in either waist circumference or blood pressure. Individuals >49 years with presence of hypertension, waist circumference of >90 and >85 cm (in males and females, respectively), and family history of diabetes had a prevalence of diabetes of 44% in the overall Population B and 11% in undiagnosed individuals.

While risk scores and screening rules have been developed previously to predict undiagnosed diabetes [19—23], most of them have been directed at largely Caucasian populations and thus are not necessarily applicable to South Asian populations, who are ethnically distinct. Some scores [24] have used biochemical profiling, which is useful for predicting the future risk of Type 2 diabetes but would be inappropriate for predicting prevalent undetected diabetes. While the Cambridge risk score [22] has been validated in Asian ethnic minorities [25], the baseline profile of the population is different from ours. The performance of our score is similar to that of the Cambridge Risk Score for

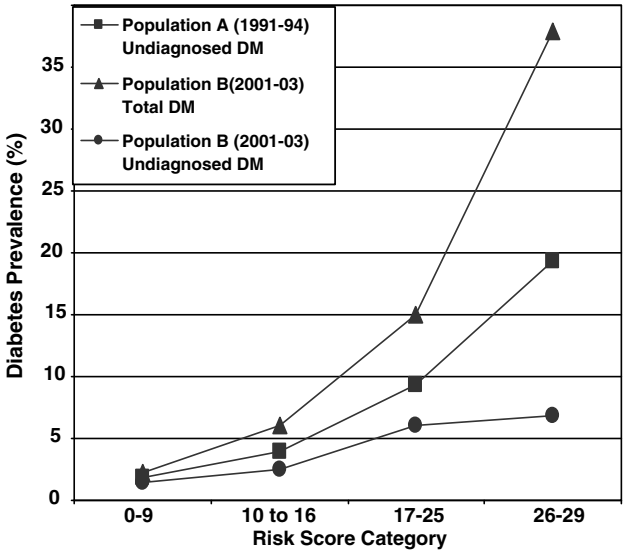

Figure 3 Diabetes Prevalence (%) according to risk score for total and undiagnosed diabetes in Populations A (1991—1994) and B (2001—2003).

Table 4 Diagnostic statistics of the risk score using a threshold score of >16 for prediction of total[a] and undiagnosed diabetes in Population A (1991—1994) and B (2001—2003)

Score	Population A	Population B	
	Undiagnosed diabetes	Total diabetes	Undiagnosed diabetes
>16	Value (95% CI)	Value (95% CI)	Value (95% CI)
Sensitivity	0.66 (0.59—0.73)	0.79 (0.77—0.82)	0.73 (0.68—0.77)
Specificity	0.67 (0.65—0.68)	0.56 (0.55—0.57)	0.56 (0.55—0.57)
Positive predictive value	0.1 (0.08—0.12)	0.17 (0.16—0.18)	0.06 (0.05—0.07)
Negative Predictive value	0.97 (0.96—0.98)	0.96 (0.95—0.97)	0.98 (0.97—0.99)
Positive Likelihood ratio	2.0 (1.8—2.0)	1.8 (1.7—1.9)	1.6 (1.5—1.7)
Negative Likelihood ratio	0.51 (0.42—0.61)	0.37 (0.33—0.42)	0.49 (0.41—0.58)

[a] Total diabetes defined as known diabetes as well as fasting hyperglycemia in those with no history of diabetes.

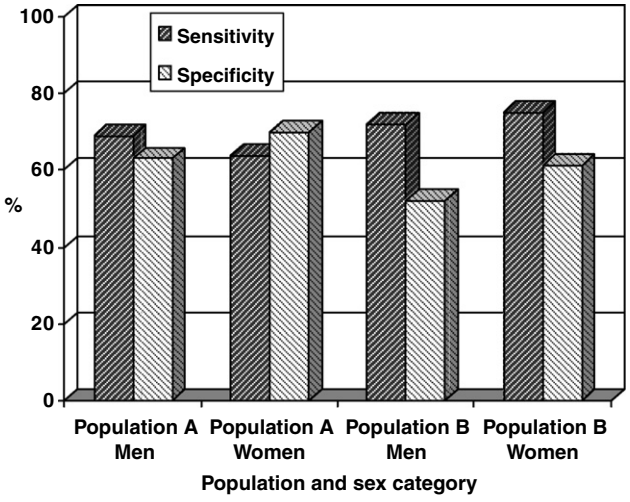

Figure 4 Sex-wise sensitivity (%) and specificity (%) of risk score threshold $\geqslant$16 to predict presence of undiagnosed diabetes in Populations A and B.

Table 5 Prevalence of cardiovascular risk factors stratified according to diabetes status and risk score >16 in individuals with undiagnosed diabetes in Population B

	True positive	False positive	False negative	True negative
Mean age (yrs)	49	46	41	35
Mean BMI (kg/m2)	27	26	22	22
Mean fasting plasma glucose (mg/dl)	163	91	169	86
Mean HDL (mg/dl)	42	43	44	44
Mean total cholesterol (mg/dl)	197	187	170	166
Mean serum triglycerides (mg/dl)	188	141	140	112
% male	66	67	70	58
Hypertension (%)	58	45	21	12
TC: HDL $\geqslant$ 4.5 (%)	53	48	37	29
Triglyceride $\geqslant$ 150 mg/dl (%)	53	35	33	19
BMI $\geqslant$ 25 kg/m^2 (%)	65	57	19	18
Metabolic Syndrome[a] (%)	88	42	39	5

[a] NCEP ATP III definition with modified waist circumference thresholds of >90 cm for men and >85 cm for women.

South Asians. Lindstrom and Tuomilehto [26] have developed a clinical risk score similar to this for prediction of future risk of Type 2 diabetes, which they also validated in cross-sectional settings for prevalent undetected diabetes. However the anthropometric cut-offs used in that Caucasian population are not applicable to the Indian population. Two risk scores have been recently reported in predominantly south Indian populations [27,28]. The diagnostic characteristics of these scores are similar to ours. However both of these risk scores included physical activity as a component, which we believe is difficult to elicit reliably in primary care settings by busy healthcare personnel. On the other hand they did not include blood pressure, which we believe is a strong risk factor associated with diabetes and helps in better characterization of individual cardiovascular risk in relation to diabetes. While our risk score was developed in a north Indian population, it was validated in a survey consisting of 10 centers across India. The performance of risk score differed when stratified according to individual centers (AUC of the ROC curve varying between 0.64 and 0.80 for total diabetes), being 0.68 and 0.68 for centers with least prevalence of diabetes (2.3% and 4.3%, respectively) and 0.68 and 0.66 for centers with highest prevalence of diabetes(16.5% and 14.5%, respectively). It is noteworthy in this regard that a recently published study in Germany [29] looking at validation of four different risk scores developed in Caucasians, found variable results, implying thereby specific characteristics that are not easily extrapolated across populations. The potential use of such a risk score needs to be weighed against a policy of uniform screening of all adults for glycemic status. As pointed out by Mohan et al. [27], substantial cost savings can be obtained with such staged high-risk targeting. Furthermore, the concept of identifying individuals with other metabolic abnormalities is also attractive.

Limitations

Our study has some limitations. There were differences in the model development and validation populations (the latter had an age range of 20—69 years, a lower proportion of females, a lower proportion of undiagnosed diabetes, and was based in a quasi-community setting), but overall the risk profile was similar. The model performed equally well, when the age range for analysis in Population B was restricted to 35—64 years to make it comparable to Population A. While the definition of diabetes in our study does not include cases that would have been detected only by post-prandial hyperglycemia or an abnormal response to glucose challenge, the score serves its purpose of identifying individuals for the next screening procedure i.e. fasting glucose. In our study, as in other populations [4], the proportion of individuals with diagnosed diabetes increased with a positive family history of diabetes and advancing age, thus weakening their association with the prevalence of undiagnosed diabetes. It is likely that in large population based settings of developing countries, the predictive ability of this risk score for undiagnosed diabetes will approximate that of total diabetes.

Increasing body mass-index (BMI) is a well known risk factor for diabetes. However the strong interaction which existed between BMI and waist circumference led to the attenuation of the predictive ability of BMI, when it was added to a model which included waist circumference. Since information about BMI is not routinely obtainable

in primary health care settings in India, we decided to keep waist circumference as the single anthropometric variable in the model. We believe that primary healthcare providers can be trained to measure waist circumference accurately. While diet, physical activity and history of gestational diabetes are known risk factors for diabetes, they were not included in the model keeping in mind that the primary healthcare providers will find it cumbersome to elicit and evaluate a detailed history of these variables.

The utility of this scoring system will depend on the health-seeking behaviours of the population as well as effective routine application of the risk score in the healthcare system. It is likely that persons aged $\geqslant$45 years seek healthcare more frequently than younger people. In such persons, application and interpretation of the risk score would be easy for healthcare providers. The score can be transformed easily into simple age-specific algorithms, for their use, as indicated earlier. These assumptions as well as the cost-effectiveness of a public health strategy incorporating a two step screening for Type 2 diabetes would, however, need to be tested in appropriately designed community studies.

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References

[1] King H, Aubert R, Herman W. Global burden of diabetes. 1995–2025: Prevalence, numerical estimates and projections. Diabetes Care 1998;21:1414–31.
[2] Ramachandran A, Snehalatha C, Latha E, Vijay V, Viswanathan M. Rising prevalence of NIDDM in an urban population in India. Diabetologia 1997;40:232–7.
[3] Ramachandran A, Snehalatha C, Dharmaraj D, Viswanathan M. Prevalence of glucose intolerance in Asian Indians: urban–rural difference and significance of upper body adiposity. Diabetes Care 1992;15:1348–55.
[4] Qiao Q, Hu G, Tuomilehto J, Nakagami T, Balkau B, Borch-Johnsen K, et al. Age- and sex-specific prevalence of diabetes and impaired glucose regulation in 11 Asian cohorts. Diabetes Care 2003;26:1770–80.
[5] Zargar AH, Khan AK, Masoodi SR, Laway BA, Wani AI, Bahir MI, et al. Prevalence of type 2 diabetes mellitus and impaired glucose tolerance in the Kashmir Valley of the Indian subcontinent. Diabetes Res Clin Pract 2000;47:135–46.
[6] Mohan V, Shanthirani CS, Deepa R. Glucose intolerance (Diabetes and IGT) in a selected South Indian population with special reference to family history, obesity and lifestyle factors – the Chennai urban population study (CUPS 14). J Assoc Physicians India 2003;51:771–7.
[7] American Diabetes Association. Screening for type 2 diabetes. Diabetes Care 2004;27(Suppl 1):S11-4.
[8] Reddy KS, Prabhakaran D, Shah P, Shah B. Differences in body mass index and waist: hip ratios in North Indian rural and urban populations. Obes Rev 2002;3:197–202.
[9] Elliott P, Stamler R. Manual of operations for ''INTERSALT'', an international cooperative study on the relation of sodium and potassium to blood pressure. Control Clin Trials 1988;9(Suppl 2):1S–117S.
[10] Reddy KS, Prabhakaran D, Chaturvedi V, Jeemon P, Thankappan KR, Ramakrishnan L, et al. Methods for establishing a surveillance system for cardiovascular diseases in Indian industrial populations. Bull World Health Organ 2006;84:461–9.
[11] O'Brien E, Petrie J, Littler WA, de Swiet M, Padfield PD, Dillon MJ. Blood pressure measurement: recommendations of the British Hypertension Society. 3rd ed. London: BMJ Publishing Group; 1997.
[12] The seventh report of the joint national committee on prevention, detection, evaluation, and treatment of high blood pressure: the JNC 7 report. JAMA 2003;289:2560–72.
[13] National Institutes of Health. Third report of the national cholesterol education program expert panel on detection, evaluation, and treatment of high blood cholesterol in adults (adult treatment panel III). Executive summary. Bethesda, MD, National Institutes of Health, National Heart, Lung and Blood Institute; 2001 (NIH publ. No. 01-3670).
[14] WHO Expert Consultation. Appropriate body-mass index for Asian populations and its implications for policy and intervention strategies. Lancet 2004;363:157–63.
[15] Snehalatha C, Viswanathan V, Ramachandran A. Cutoff values for normal anthropometric variables in Asian Indian adults. Diabetes Care 2003;26:1380–4.
[16] Alberti KG, Zimmet P, Shaw J. IDF epidemiology task force consensus group. The metabolic syndrome – a new worldwide definition. Lancet 2005;366:1059–62.
[17] Lowry R. Clinical calculator 1 from an observed sample: estimates of population prevalence, sensitivity, specificity, predictive values, and likelihood ratios, <http://www.faculty.vassar.edu/lowry/clin1.html>; 2001 [accessed 15.08.2006].
[18] Yajnik CS. The insulin resistance epidemic in India: fetal origins, later lifestyle, or both. Nutr Rev 2001;59:1–9.
[19] Herman WH, Smith PJ, Thompson TJ, Engelgau MM, Aubert RE. A new and simple questionnaire to identify people at increased risk for undiagnosed diabetes. Diabetes Care 1995;18:382–7.
[20] Ruige JB, de Neeling JN, Kostense PJ, Bouter LM, Heine RJ. Performance of an NIDDM screening questionnaire based on symptoms and risk factors. Diabetes Care 1997;20:491–6.

[21] Baan CA, Ruige JB, Stolk RP, Wittrman JC, Dekker JM, Heine RJ, et al. Performance of a predictive model to identify undiagnosed diabetes in a health care setting. Diabetes Care 1999;22:213—9.
[22] Griffin SJ, Little PS, Hales CN, Kinmonth AL, Wareham NJ. Diabetes risk score: towards earlier detection of type 2 diabetes in general practice. Diabetes Metab Res Rev 2000;16:164—71.
[23] Park PJ, Griffin SJ, Sargeant L, Wareham NJ. The performance of a risk score in predicting undiagnosed hyperglycemia. Diabetes Care 2002;25:984—8.
[24] Stern MP, Williams K, Haffner SM. Identification of persons at high risk for type 2 diabetes mellitus: do we need the oral glucose tolerance test. Ann Intern Med 2002;136:575—81.
[25] Spijkerman AM, Yuyun MF, Griffin SJ, Dekker JM, Nijpels G, Wareham NJ. The performance of a risk score as a screening test for undiagnosed hyperglycemia in ethnic minority groups: data from the 1999 health survey for England. Diabetes Care 2004;27:116—22.
[26] Lindstrom J, Tuomilehto J. The diabetes risk score: a practical tool to predict type 2 diabetes risk. Diabetes Care 2003;26:725—31.
[27] Mohan V, Deepa R, Deepa M, Somannavar S, Datta M. A simplified Indian diabetes risk score for screening for undiagnosed diabetic subjects. J Assoc Physicians India 2005;53:759—63.
[28] Ramachandran A, Snehalatha C, Vijay V, Wareham NJ, Colagiuri S. Derivation and validation of diabetes risk score for urban Asian Indians. Diabetes Res Clin Pract 2005;70:63—70.
[29] Rathmann W, Martin S, Haastert B, Icks A, Holle R, Lowel H, et al. Performance of screening questionnaires and risk scores for undiagnosed diabetes: the KORA Survey 2000. Arch Intern Med 2005;165:436—41.