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Diabetes care cascade and associated factors in 10,700 middle-aged adults in four sub-Saharan African countries

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Full title: Diabetes care cascade and associated factors in 10,700 middle-aged adults in four sub-Saharan African countries

Running title: Diabetes care cascade in sub-Saharan Africa

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Abstract

Introduction: Prevalent diabetes-associated morbidity and mortality in sub-Saharan Africa reflect the failure of the health care system to appropriately identify and manage patients with diabetes. We investigated progression through the care cascade and associated factors for people with diabetes in sub-Saharan Africa to identify attrition stages that may be most appropriate for targeted intervention.

Research Design and Methods: Data were analysed from 10,700 individuals, aged 40-60 years, in a community-based, cross-sectional study in four sub-Saharan African countries. Age-adjusted diabetes prevalence (self-report, fasting plasma glucose [FPG]≥7 mmol/l or random plasma glucose≥11.1 mmol/l) was calculated and proportions of those who reported awareness of having diabetes and receiving treatment were sequentially determined. Diabetes control (FPG<7.2 mmol/l) was calculated as a proportion of those receiving treatment. Logistic regression was used to investigate factors associated with having diabetes and being aware of the diagnosis.

Results: Diabetes prevalence was 5.5% (95%CI 4.4-6.5%). Approximately half of those with diabetes were aware (54%; 95%CI 50-58%); 73% (95%CI 67-79%) of aware individuals reported treatment. However, only 38% (95%CI 30-46%) of those treated were adequately controlled. Older age (OR 1.1; 95%CI 1.0-1.1), urban residence (OR 2.3; 95%CI 1.6-3.5), hypertension (OR 1.9; 95%CI 1.5-2.4), family history of diabetes (OR 3.9; 95%CI 3.0-5.1), and measures of central adiposity were associated with higher odds of having diabetes. Older age (OR 1.1; 95%CI 1.0-1.1), semi-rural residence (OR 2.5; 95%CI 1.1-5.7), secondary education (OR 2.4; 95%CI

1.2-4.9), hypertension (OR 1.6; 95%CI 1.0-2.4), and HIV (OR 2.3; 95%CI 1.2-4.4) were associated with greater likelihood of awareness.

Conclusions: There is attrition at each stage of the diabetes care cascade in sub-Saharan Africa. Public health strategies should target improving diagnosis in high-risk individuals and intensifying therapy in individuals treated for diabetes.

Keywords: diabetes mellitus, sub-Saharan Africa

KEY MESSAGES

What is already known on this topic?

The prevalence of diabetes in sub-Saharan Africa is expected to increase dramatically while diabetes-related morbidity and mortality in the region remain high.

What this study adds?

Just over half of individuals with diabetes in this cross-sectional multi-country study of 10,700 adults in sub-Saharan Africa were aware of their condition and while 73% reported receiving treatment, fewer than 40% of those receiving treatment achieved glycaemic targets.

How might this study affect research, practice or policy?

Focus should be placed on diagnosing diabetes in at-risk individuals and intensifying therapy in those already diagnosed with diabetes in sub-Saharan Africa.

INTRODUCTION

Sub-Saharan Africa (SSA) is projected to experience a 143% increase in diabetes prevalence by 2045.[1] Inadequate control of blood sugar and other cardiovascular risk factors will impose an unsustainable burden of diabetes-related complications on already constrained regional health care systems. Existing data suggest that outcomes in individuals in SSA with diabetes are currently suboptimal with over 350,000 diabetes-related deaths in 2019,[1] highlighting the need to improve clinical care. Optimisation of diabetes management is contingent on numerous factors including the diagnosis of diabetes, appropriate escalation of therapy and patient adherence to therapeutic interventions, but effective strategies to improve diabetes management in SSA are hampered by a lack of knowledge about the extent of the deficiencies in this care continuum.

The cascade of care model, frequently used to identify deficits in HIV care, may be applied to diabetes to identify opportunities for improved outcomes.[2] The elements of the cascade namely prevalence, awareness, treatment and control reflect aspects of the health care system, including effectiveness of prevention and detection strategies and the ability to implement and escalate therapy as necessary. On an individual level, diabetes awareness in particular is key to the adherence to lifestyle modification and medication that underpin glycaemic control. Evaluation of the diabetes care cascade allows policy makers to assess how well the health care system manages patients with diabetes and to identify areas for targeted interventions, particularly important in the resource-constrained lower and middle-income countries of SSA.

Despite the benefits of establishing the diabetes care cascade, there is a paucity of primary data on it in SSA. Studies have often been limited to diabetes prevalence and awareness and conducted in hospital-based populations, introducing selection bias, while multi-country studies that have reported on the entire cascade have meta-analysed data from heterogeneous studies with methodological differences in determining each cascade stage. We aimed to evaluate the diabetes cascade of care in four SSA countries, using harmonised data collected across six sites. We further investigated factors associated with the likelihood of having diabetes and being aware of a diagnosis of diabetes, the first two steps in the cascade.

METHODS

Study Setting and Participants

The AWI-Gen study and participating sites have been described in detail elsewhere.[3,4] In brief, 10,700 individuals, aged 40-60 years, were recruited from six sites in SSA in a community-based, cross-sectional study conducted between August 2013 and August 2016. Three of these sites were in South Africa (Soweto, Agincourt and Dikgale), one was in Kenya (Nairobi), one in Ghana (Navrongo) and one in Burkina Faso (Nanoro). Participants were therefore included from southern, eastern and western Africa. The selected sites were also on a continuum of urbanisation: Nairobi and Soweto were urban sites, Agincourt and Dikgale were semi-rural and Nanoro and Navrongo were rural.

With the exception of Soweto, each study site is home to a Health and socio-Demographic Surveillance System (HDSS) which enumerates all residents within the HDSS on a regular basis, ensuring a well-defined population sampling frame. In

Nairobi, Agincourt, Navrongo and Nanoro, individuals were randomly sampled from the sampling frame, while in Dikgale, a convenience sampling strategy was employed. In Soweto, 700 women who were participants in the Study of Women Entering an Endocrine Transition (SWEET) study[5] and caregivers of the Birth to Twenty+ cohort[6] were recruited. Additional female and all male participants were randomly recruited, using a sampling frame which covered the Soweto region. Where necessary, there was oversampling to ensure equal numbers of women and men.

Ethical Considerations

Written informed consent was provided by participants in their local languages. Ethical approval for the AWI-Gen study was provided by the Human Research Ethics Committee (Medical) of the University of the Witwatersrand (M121029, M170880). Each of the HDSS centres also obtained ethical approval according to their respective institutional and country-specific regulations.

Patient and public involvement

Prior to the initiation of the AWI-Gen studies, an extensive process of community engagement was conducted. This included meetings with civic and traditional leadership structures, household visits and group information sessions to discuss planned research activities. Study results were delivered annually to study participants, communities and community leaders.

Data Collection and Definitions

Data were collected by study staff trained on standardised protocols. Sociodemographic data and personal and family medical history were self-reported. Additionally, individuals were considered to have hypertension if the mean systolic blood pressure of the latter two of three readings at the study visit ≥140 mmHg or the mean diastolic pressure ≥90 mmHg (Omron M6, Omron, Kyoto, Japan). Individuals were classified as HIV positive if they reported a previous diagnosis of HIV or if they tested positive on the rapid HIV tests that were offered to participants in South Africa and Kenya (MD HIV 1/2 test [Medical Diagnostech, Cape Town, South Africa]; One Step anti-HIV1+2 rapid screen test [InTec, Xiamen, China]; Determine rapid test kit [Abbot Pharmaceuticals, Chicago, USA]). Rapid HIV tests were not offered in Ghana and Burkina Faso due to the low prevalence of HIV in those countries; individuals in these sites who did not know their HIV status were classified as HIV negative. Physical activity was assessed using the Global Physical Activity Questionnaire and occupational, leisure time and travel-related physical activity variables from this questionnaire were summed to give the total moderate-vigorous intensity physical activity (MVPA) in minutes per week. Individuals were classified as having no MVPA (0 minutes/week), insufficient MVPA (1-150 minutes/week) or sufficient MVPA (≥150 minutes/week).[7]

Standing height was measured with the participant barefoot or in light socks, using a Harpenden digital stadiometer (Holtain, Wales, UK). Weight was measured with the participant in light clothing, using a digital Physician Large Dial 200 kg capacity scale (Kendon Medical, South Africa) and body mass index was calculated as weight in kg divided by height in metres squared. Using a stretch-resistant measuring tape

(SECA, Hamburg, Germany), hip circumference, as a measure of gluteofemoral fat, was measured around the most protruding part of the buttocks.

Visceral and subcutaneous adipose tissue, direct measures of central adiposity associated with insulin resistance, were measured using abdominal ultrasound (LOGIQ e ultrasound system [GE Healthcare, CT, USA]). Visceral adipose thickness was determined by the thickness of the fat pad between the anterior spine and peritoneal layer at end expiration, while subcutaneous adipose thickness was the thickness of the fat pad between the skin and the outer edge of the linea alba.

Venous blood was collected in potassium oxalate/sodium fluoride tubes and centrifuged after collection, with the supernatant plasma stored at -80°C until analysis. Analyses for glucose were all performed at a central site, using colorimetric methods, on the Randox Plus clinical chemistry analyser (Randox, UK) with a range of 0.36–35 mmol/l and coefficient of variation<2.3%.

Diabetes was defined as a previous diagnosis of diabetes by a health care provider, ever having received treatment for diabetes, or fasting plasma glucose ≥7 mmol/l or random plasma glucose ≥11.1 mmol/l on the sample taken during the study visit. Samples were considered random if a participant had not fasted overnight or fasting status could not be confirmed. Participants were considered to be aware of a diagnosis of diabetes if they reported ever having been told by a health professional that they had diabetes and were considered to have been treated for diabetes if they reported ever having received treatment for diabetes (dietary advice and/or glucose

lowering agents) from a health care professional. Individuals were considered to have their diabetes controlled if fasting glucose was <7.2 mmol/l.[8]

Statistical Analysis

Categorical participant characteristics were described using frequencies and percentages, while medians and interquartile ranges (IQR) were used to describe continuous characteristics. The Mann-Whitney U, chi-squared and Fisher's exact tests were used to compare continuous and categorical variables respectively between groups defined by sex and missingness status.

Age-adjusted diabetes prevalence was determined using the United Nations African population distribution[9] as the reference population structure. The proportion of those aware of having diabetes was calculated as a percentage of those with diabetes and similarly, the proportion of those receiving treatment for diabetes was calculated as a percentage of those aware of having diabetes; the proportion of those who had their diabetes controlled was calculated as a percentage of those who reported receiving treatment. The method for interval estimation described by Tiwari et al.[10] was used to determine the 95% confidence intervals.

Multivariable logistic regression was used to assess the relationship between the odds of having diabetes and sociodemographic and clinical characteristics including urbanicity; independent variables were selected based on previous research.[11,12] The Soweto site did not collect data on family history of diabetes and was therefore not included in this model. Additional multivariable logistic regression models were also fit, using data from all sites, to investigate associations with awareness of a

diagnosis of diabetes. In the model investigating associations with odds of having diabetes, we included visceral and subcutaneous fat as direct assessments of central obesity and hip circumference as a measure of gluteofemoral fat. In the model investigating associations with awareness, we used body mass index as the measure of obesity as we thought awareness was more likely to be associated with a global assessment of obesity rather than individual fat depots. We were underpowered to assess associations with diabetes treatment and control.

Sensitivity analyses were conducted in which associations with having diabetes and awareness of a diagnosis of diabetes were explored in analyses stratified by HIV prevalence, with the South African sites and Nairobi classified as high prevalence sites and Navrongo and Nanoro classified as low prevalence sites.

Missing data were handled using pairwise deletion. Analyses were conducted using STATA v16 (StataCorp, USA).

RESULTS

Sample Characteristics

The characteristics of the 10,700 study participants are shown in Table 1. There were 5,892 women (55%), with a median age of 50 years (IQR 45-55). There was some inter-site variation in sociodemographic variables - while most participants in the urban and semi-rural sites had some formal education, between 70-80% of participants in the rural sites did not. Smoking prevalence ranged between 6% and 30% overall, with prevalence several fold higher in men than in women in all sites. There was a high prevalence of chronic disease with 3,755 (37%) participants having

hypertension and 1,310 (12%) having HIV, although inter-site variation was evident, with HIV prevalence being low, for example, in Nanoro and Navrongo. Family history of diabetes was highest in the urban and semi-rural areas. Anthropometric measures of obesity and subcutaneous fat were higher in women in urban and semi-urban areas, while there were no clear sex differences in Nanoro and Navrongo. Visceral fat was generally similar in both sexes. The majority of individuals (82%) were undertaking at least 150 minutes of moderate to vigorous physical activity weekly.

Table 1. Demographic and clinical characteristics of 10,700 study participants in six sub-Saharan African sites

	Soweto			Agincourt			Dikgale			Nanoro			Navrongo			Nairobi			Overall		
	Men	Women	Overall	Men	Women	Overall	Men	Women	Overall	Men	Women	Overall	Men	Women	Overall	Men	Women	Overall	Men	Women	Overall
	n=1,025 51%	n=1,002 49%	n=2,027	n=573 39%	n=892 61%	n=1,465	n=356 31%	n=812 69%	n=1,168	n=1,045 50%	n=1,039 50%	n=2,084	n=923 46%	n=1,091 54%	n=2,014	n=886 46%	n=1,056 54%	n=1,942	n=4,808 45%	n=5,892 55%	n=10,700
Age (years)	49 (44-55)	49 (44-54)	49 (44-54)	51 (45-56)	51 (46-56)	51 (46-56)	50 (45-55)	51 (46-56)	51 (45-55)	50 (44-55)	50 (45-54)	50 (45-55)	50 (46-55)	52 (47-56)	51 (46-56)	48 (44-53)	48 (44-52)	48 (44-53)	50 (45-55)	50 (45-55)	50 (45-55)
Marital status (%)																					
Currently married/ cohabitating	570 (56)	266 (27)	836 (41)	445 (78)	537 (60)	982 (67)	178 (50)	427 (53)	605 (52)	1,021 (98)	794 (76)	1,815 (87)	787 (85)	694 (64)	1,481 (74)	808 (91)	486 (46)	1,294 (67)	3,809 (79)	3,204 (54)	7,013 (66)
Never married/ cohabitating	265 (26)	51 (5.1)	316 (16)	75 (13)	59 (6.6)	134 (9.2)	103 (29)	185 (23)	288 (25)	14 (1.3)	3 (0.3)	17 (0.8)	15 (1.6)	5 (0.5)	20 (1.0)	13 (1.5)	70 (6.6)	83 (4.3)	485 (10)	373 (6.3)	858 (8.0)
Previously married	189 (19)	347 (35)	536 (26)	53 (9.2)	296 (33)	349 (24)	75 (22)	200 (25)	275 (24)	8 (0.8)	238 (23)	246 (12)	120 (13)	392 (36)	512 (26)	65 (7.3)	499 (47)	564 (29)	510 (11)	1,972 (33)	2,482 (23)
Missing	1 (0.1)	338 (34)	339 (17)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	2 (0.2)	4 (0.4)	6 (0.3)	1 (0.1)	0 (0)	1 (0.1)	0 (0)	1 (0.1)	1 (0.1)	4 (0.1)	343 (5.8)	347 (3.2)
Highest level of education (%)																					
No formal education	8 (0.8)	2 (0.2)	10 (0.5)	23 (22)	280 (31)	403 (28)	22 (6.2)	74 (9.1)	96 (8.2)	758 (73)	960 (92)	1,718 (82)	570 (62)	843 (77)	1,413 (70)	34 (3.8)	113 (11)	147 (7.6)	1,515 (32)	2,272 (39)	3,787 (35)
Primary education	117 (11)	636 (64)	753 (37)	235 (41)	340 (38)	575 (39)	113 (32)	273 (34)	386 (33)	181 (17)	58 (5.6)	239 (12)	206 (22)	177 (16)	383 (19)	447 (51)	663 (63)	1,110 (57)	1,299 (27)	2,147 (36)	3,446 (32)
Secondary education	748 (73)	147 (15)	895 (44)	175 (31)	223 (25)	398 (27)	204 (57)	440 (54)	644 (55)	86 (8.2)	10 (1)	96 (4.6)	118 (13)	57 (5.2)	175 (8.7)	383 (43)	276 (26)	659 (34)	1,714 (36)	1,153 (20)	2,867 (27)
Tertiary education	152 (15)	1 (0.1)	153 (7.5)	39 (6.8)	49 (5.5)	88 (6.0)	17 (4.8)	24 (3.0)	41 (3.5)	16 (1.5)	2 (0.2)	18 (0.9)	27 (2.9)	9 (0.8)	36 (1.8)	22 (2.5)	4 (0.4)	26 (1.3)	273 (5.7)	89 (1.5)	362 (3.4)
Missing	0 (0)	216 (22)	216 (10.7)	1 (0.2)	0 (0.0)	1 (0.1)	0 (0)	1 (0.1)	1 (0.1)	4 (0.4)	9 (0.9)	13 (0.6)	2 (0.2)	5 (0.5)	7 (0.4)	0 (0)	0 (0)	0 (0)	7 (0.2)	231 (3.9)	238 (2.2)
Employed (%)	670 (65)	547 (55)	1,217 (60)	197 (34)	303 (34)	500 (34)	160 (45)	279 (34)	439 (37)	1,026 (98)	1,030 (99)	2,056 (99)	599 (65)	659 (60)	1,258 (63)	860 (97)	966 (92)	1,826 (94)	3,512 (73)	3,784 (64)	7,296 (68)
Current smoker (%)	540 (53)	49 (4.9)	589 (29)	155 (27)	3 (0.3)	158 (11)	225 (63)	25 (3.1)	250 (21)	142 (14)	0 (0)	142 (6.8)	388 (42)	21 (1.9)	409 (20)	208 (24)	27 (2.6)	235 (12)	1,658 (35)	125 (2.1)	1,783 (17)
Hypertension (%)	550 (54)	552 (55)	1102 (54)	251 (44)	517 (58)	768 (52)	116 (33)	392 (49)	508 (44)	215 (21)	127 (12)	342 (17)	227 (25)	274 (25)	501 (25)	204 (23)	319 (30)	523 (27)	1,563 (33)	2,181 (37)	3,744 (35)
HIV positive (%)	189 (18)	121 (12)	310 (15)	186 (33)	304 (34)	490 (33)	73 (21)	175 (22)	248 (21)	5 (0.5)	4 (0.4)	9 (0.4)	9 (1.0)	6 (0.6)	15 (0.7)	67 (7.6)	171 (16)	238 (12)	529 (11)	781 (13)	1,310 (12)

Family history of diabetes (%)	NA	NA	NA	85 (15)	161 (18)	246 (17)	53 (15)	134 (17)	187 (16)	24 (2.3)	12 (1.2)	36 (1.7)	12 (1.3)	10 (0.9)	22 (1.1)	112 (13)	213 (20)	325 (17)	286 (6.0)	530 (9.0)	816 (7.6)
Body mass index (kg/m^2)	24.2 (20.6-28.5)	32.9 (28.5-37.6)	28.4 (23-33.9)	23 (20.3-26.6)	28.6 (24.1-33.2)	26 (22.1-31.3)	20.6 (18.9-24.1)	30.1 (25.3-35.9)	26.9 (21.1-33.1)	21.1 (19.2-23.4)	19.8 (18.1-21.6)	20.4 (18.6-22.6)	20.6 (19-22.3)	21.4 (19.6-23.9)	21 (19.3-23.1)	22.2 (20-25)	26.9 (23-31.7)	24.4 (21.1-28.6)	21.7 (19.5-24.9)	25.5 (20.8-31.9)	23.2 (20.1-28.6)
Hip circumference (cm)	97.4 (90.0-105.3)	117.5 (109.0-127.0)	107.0 (95.7-118.5)	94.0 (89.0-102.0)	105.0 (97.0-113.0)	100.0 (93.0-110.0)	87.6 (83.3-94.9)	108.7 (98.5-118.9)	101.9 (90.1-114.3)	89.5 (85.6-94.9)	87.8 (83.4-92.5)	88.8 (84.5-93.7)	83.0 (79.0-88.0)	88.0 (83.0-94.0)	86.0 (81.0-91.0)	93.0 (87.4-98.9)	101.0 (94.0-110.0)	97.0 (90.0-104.6)	90.6 (85.0-98.0)	99.0 (89.0-112.0)	94.2 (86.6-105.3)
Subcutaneous fat (cm)	1.4 (0.9-2.0)	.1 (2.5-3.9)	2.2 (1.3-3.2)	1.2 (0.7-1.7)	2.2 (1.5-3.0)	1.7 (1.1-2.7)	0.8 (0.5-1.2)	2.2 (1.6-2.9)	1.7 (0.9-2.6)	0.8 (0.6-1.2)	0.9 (0.6-1.2)	0.9 (0.6 1.2)	0.7 (0.5-0.9)	1.0 (0.7-1.5)	0.8 (0.6-1.2)	1.0 (0.7-1.5)	2.0 (1.4-2.4)	1.5 (1.0-2.1)	0.9 (0.6-1.4)	1.7 (1.0-2.6)	1.2 (0.8-2.1)
Visceral fat (cm)	6.2 (5-7.8)	4.7 (3.5-5.9)	5.5 (4.2-6.9)	6.3 (5.2-7.8)	5.9 (4.2-7.3)	6.1 (4.6-7.5)	5.9 (4.7-7.4)	6.7 (4.9-8.5)	6.4 (4.9-8.2)	4.3 (3.5-5.2)	4.3 (3.6-5.1)	4.3 (3.5-5.1)	4 (3.3-4.8)	3.3 (2.8-4.1)	3.6 (3-4.5)	5 (3.9-6.3)	4.6 (3.6-5.8)	4.8 (3.7-6)	5 (3.9-6.5)	4.5 (3.4-6)	4.7 (3.6-6.2)
Physical activity categories (%)																					
Absent	63 (6.2)	167 (17)	230 (11)	106 (19)	143 (16)	249 (17)	3 (0.9)	8 (1)	11 (1.3)	227 (22)	110 (11)	337 (16)	64 (7.1)	154 (14)	218 (11)	6 (0.7)	19 (1.8)	25 (1.3)	469 (9.8)	601 (10)	1,070 (10)
Insufficient	134 (13)	283 (28)	417 (21)	21 (3.7)	58 (6.5)	79 (5.4)	16 (4.5)	27 (3.3)	134 (6.9)	37 (3.5)	34 (3.3)	71 (3.4)	35 (3.9)	59 (5.4)	94 (4.7)	41 (4.6)	93 (8.8)	134 (6.9)	284 (5.9)	554 (9.4)	838 (7.9)
Sufficient	828 (81)	552 (55)	1,380 (68)	443 (78)	686 (77)	1,129 (78)	334 (95)	776 (96)	1,780 (92)	781 (75)	895 (86)	1,676 (80)	807 (89)	874 (80)	1,681 (84)	839 (95)	941 (89)	1,780 (92)	4,032 (84)	4,724 (80)	8,756 (82)

Continuous variables are summarised as medians and interquartile ranges and categorical variables as n (%); NA-not applicable

Missing Outcome Data

No participants had missing data on the diabetes status outcome, while 31 individuals had missing data on the awareness outcome and were slightly older (median age 54 vs 52 years; p=0.035), less likely to be employed (32 vs 64%; p=0.001) and had a different marital status distribution (p=0.005) than those who were not missing these data.

Diabetes Cascade of Care

The diabetes cascade of care is shown in Figure 1. The age-adjusted prevalence of diabetes in study participants was 5.5% (95%CI 4.4-6.5%) and was significantly higher in women (6.1% vs 4.9%; p=0.004). Prevalence varied by site, with highest prevalence in the urban site of Soweto (9.0%; 95%CI 7.8-10%) and the lowest in rural Navrongo (1.3%; 95%CI 0.7-1.9%) (Supplemental Table S1). Diabetes prevalence was higher in women than men in Soweto and Nairobi (Soweto: 12% vs 6.3%, p<0.001; Nairobi: 9.1% vs 4.1%, p<0.001) while in Nanoro, the prevalence was higher in men (1.8% vs 4.7%, p<0.001).

Overall, just over half of the 613 individuals with diabetes were aware of their condition (54%; 95%CI 50-58%), with the highest awareness in Navrongo (65%; 95%CI 43-84%) and the lowest in Nanoro (25%; 95%CI 16-37%), although confidence intervals across the sites were wide and overlapping. Nearly 75% of individuals aware of having diabetes reported receiving treatment, but only 38% (95%CI 30-41%) were adequately controlled. More women reported being treated for diabetes (p=0.013), but there were no sex differences in participants achieving control (p=0.978).

In logistic regression models, older age (odds ratio [OR] 1.1; 95%CI 1.0-1.1; p<0.001) and urban residence (OR 2.3; 95%CI 1.6-3.5; p<0.001) were associated with higher odds of having diabetes (Table 2). Hypertension was also associated with having diabetes (OR 1.9; 95%CI 1.5-2.4; p<0.001), as was family history of diabetes (OR 3.9; 95%CI 3.0-5.1; p<0.001); conversely, HIV was associated with lower odds of diabetes (OR 0.6; 95%CI 0.4-0.9; p<0.001). Visceral and subcutaneous fat were also associated with higher odds, while there was a marginal negative association with hip circumference.

Similar associations were evident in sensitivity analyses restricted to sites with high HIV prevalence (Supplemental Table S2). However, only family history remained significantly associated with diabetes in low HIV prevalence settings, although previously unobserved associations with male sex and physical activity emerged (Supplemental Table S3). These analyses were however limited by the low prevalence of diabetes in these settings which meant they were underpowered.

Older age (OR 1.1; 95%CI 1.0-1.1; p=0.019), semi-rural environment (OR 2.5; 95%CI 1.1-5.7; p=0.022) and secondary education (OR 2.4; 95%CI 1.2-4.9; p=0.015) were all associated with greater likelihood of awareness of diabetes, as were the chronic conditions hypertension (OR 1.6; 95%CI 1.0-2.4; p=0.039) and HIV (OR 2.3; 95%CI 1.2-4.4; p=0.017) (Table 3). In sensitivity analyses in high HIV prevalence sites, only hypertension and HIV remained associated with higher awareness of diabetes (Supplemental Table S4). The sample size in low HIV prevalence sites was too small to perform meaningful analyses.

Table 2. Factors associated with odds of having diabetes in five sub-Saharan African sites (Agincourt, Dikgale, Nairobi, Nanoro & Navrongo)[1]

	Odds Ratio	95% confidence interval	p value
Age	1.1	1.0-1.1	<0.001
Sex			
Women	reference		
Men	1.1	0.8-1.5	0.649
Location			
Rural	reference		
Semi-rural	1.5	1.0-2.3	0.077
Urban	2.3	1.6-3.5	<0.001
Marital status			
Currently married or cohabitating	reference		
Never married or cohabitating	1.4	0.9-2.0	0.152
Previously married	1.0	0.8-1.3	0.991
Educational attainment			
No formal education	reference		
Primary education	1.2	0.9-1.7	0.293
Secondary education	1.0	0.7-1.5	0.840
Tertiary education	1.4	0.7-2.6	0.372
Employment status			
Unemployed	reference		
Employed	1.1	0.8-1.5	0.480
Smoking status			
No history of smoking	reference		
Current smoker	0.7	0.4-1.1	0.151
History of hypertension			
No	reference		
Yes	1.9	1.5-2.4	<0.001
HIV status			
Negative	reference		
Positive	0.6	0.4-0.9	0.009
Family history of diabetes			
No	reference		
Yes	3.9	3.0-5.1	<0.001
Physical activity categories			
Absent	reference		
Insufficient	0.9	0.5-1.5	0.610
Sufficient	0.7	0.5-1.0	0.078
Hip circumference	1.0	1.0-1.0	0.044
Visceral fat	1.2	1.1-1.2	<0.001
Subcutaneous fat	1.3	1.1-1.4	<0.001

[1]7,425 participants were included in the analysis. Participants from the Soweto site were excluded as data on family history were not collected

Table 3. Factors associated with awareness of diabetes in six sub-Saharan African sites (Agincourt, Dikgale, Nairobi, Nanoro, Navrongo & Soweto)[1]

	Odds Ratio	95% confidence interval	p value
Age	1.0	1.0-1.1	0.019
Sex			
Women	reference		
Men	1.1	0.7-1.8	0.586
Location			
Rural	reference		
Semi-rural	2.5	1.1-5.7	0.022
Urban	1.5	0.7-3.1	0.345
Marital status			
Currently married or cohabitating	reference		
Never married or cohabitating	0.9	0.4-2.0	0.844
Previously married	1.0	0.6-1.7	0.863
Educational attainment			
No formal education	reference		
Primary education	1.8	0.9-3.5	0.086
Secondary education	2.4	1.2-4.9	0.015
Tertiary education	2.1	0.7-6.1	0.168
Employment status			
Unemployed	reference		
Employed	0.8	0.5-1.3	0.449
History of hypertension			
No			
Yes	1.6	1.0-2.4	0.039
HIV status			
Negative	reference		
Positive	2.3	1.2-4.4	0.017
Body mass index	1.0	1.0-1.0	0.968

[1]472 participants were included in the analysis

DISCUSSION

In this multi-country study of the diabetes care cascade in SSA, we demonstrate attrition at each stage of the cascade with just over half of those with diabetes being aware of their condition and only approximately a third of those who reported treatment achieving optimal glycaemic control.

Our prevalence estimate of 5.5% is similar to the 2019 International Diabetes Federation (IDF) estimate for SSA of 4.7% in adults aged 20-79 years.[1] A sub-

regional meta-analysis from western Africa revealed a lower prevalence (4.0% in urban adults and 2.6% in rural adults),[13] in keeping with our study where prevalence in the western African sites was two to three times lower than in the southern and eastern African sites. Factors in our study associated with higher odds of having diabetes, such as age and urban residence, have been previously reported, with the western African meta-analysis reporting over a threefold increase in prevalence in people over 50 years[13] and Werfalli et al. reporting a prevalence of 20% in people living in urban areas vs 7.9% in those in rural areas.[14] Our findings of associations with family history of diabetes, hypertension and adiposity support results from other country-level meta-analyses in Africa.[15,16] We also noted lower odds of having diabetes in individuals with HIV in keeping with other studies that have identified lower prevalence of cardiometabolic risk factors in individuals with HIV in SSA.[17,18]

While our estimate of the prevalence of diabetes unawareness of 47% was broadly similar to the 2019 IDF estimate of the prevalence of undiagnosed diabetes of 60% in SSA,[1] it did contrast sharply with other studies. A meta-analysis of 23 studies from across Africa estimated a much lower pooled prevalence of undiagnosed diabetes of just under 4%.[19] There was however significant heterogeneity in the included studies and the majority of the data originated from a single country, which may not be representative of other countries in the region. This itself differed considerably from data from 12 nationally representative surveys in SSA in which 73% of those with diabetes were unaware of their condition, with factors similar to our study, namely older age and higher level of educational attainment, associated with awareness.[20]

Comparison of our results with a previous meta-analysis from SSA which reported approximately 11% of individuals with diabetes receiving treatment with insulin and 25% receiving oral hypoglycaemic agents is limited as different denominators were used.[20] A country-level meta-analysis of 22 studies from Ethiopia suggested a similar degree of glycaemic control as our study, with approximately a third of those included achieving glycaemic targets, regardless of whether these were assessed using fasting plasma glucose or glycosylated haemoglobin (HbA_{1c}).[21]

We describe, to our knowledge, the first study in SSA in which harmonised primary data on the diabetes care cascade have been collected from multiple countries. Previous multi-country research in SSA on this subject has relied on systematic reviews and meta-analyses and has therefore been limited by the methodological heterogeneity of the constituent studies. In our work, data were collected in a standardised manner and in addition to self-report, we used venous blood samples, analysed at a single laboratory, to ascertain biochemical evidence of diabetes. Our study also included over 10,000 men and women from three sub-regions of SSA and therefore allows comparison between sub-regions as well as overall estimates.

Our study does have limitations. We did not distinguish between type 1 and type 2 diabetes and the care cascade and associated factors may differ between these two conditions. While we used accepted and convenient diagnostic criteria for diabetes, we may have underestimated the prevalence of diabetes as we did not assess glucose tolerance and may therefore have excluded those who met the criteria for diabetes only after a glucose load, which may be particularly important in populations

of African descent. Both oral glucose tolerance tests and HbA_{1c}, appear to classify more African-ancestry individuals as having diabetes than FPG alone [22, 23] and use of either of these criteria may have increased diabetes prevalence in our study. Our research was conducted in HDSS sites and among a research cohort in Soweto, populations which may not be nationally representative. Indeed, previous studies in these sites may have increased awareness of diabetes beyond that in the general population. We also used self-report rather than clinical records to determine diabetes treatment. Fasting plasma glucose was used to assess diabetes control and this provides an evaluation only at a single point in time and may be subject to more analytic variability than HbA_{1c}, which has largely supplanted it in clinical use in well-resourced environments.

Despite these limitations, our study provides valuable information on the burden of diabetes in SSA and the deficiencies which need to be addressed to improve outcomes. In areas where diabetes prevalence is low, primordial prevention strategies should be employed to reduce the likelihood of developing risk factors such as obesity, with particular focus on higher risk urban environments. Screening of at-risk populations needs to be enhanced and the low percentage of individuals attaining satisfactory glycaemic control suggests that more aggressive, treat to target strategies need to be promoted among health care workers, although we acknowledge this may be limited by drug availability in many parts of the continent.

Additional work is necessary to understand whether our findings are applicable to other SSA countries and sub-regions at different stages of the epidemiological transition and with variable access to health care. It is also essential to understand

key determinants of diabetes treatment and control, which we were underpowered to investigate, and care cascades for other important vascular risk factors in people with diabetes, such as elevated blood pressure and dyslipidaemia. Identification of the points in each of these care cascades at which significant attrition is occurring will assist public health officials in developing appropriate interventions to reduce diabetes-related morbidity and mortality.

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ANW and MR had full access to all the data in the study and take responsibility for the integrity of the data. IM performed the data analysis and takes responsibility for its accuracy. All authors consent to the publication of this manuscript and agree to be accountable for all aspects of this work.

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Data statement: De-identified individual participant data from the AWI-Gen study are available from the European Genome-Phenome Archive (EGA) at study number EGA00001002482 [https://ega459 archive.org/datasets/EGAD00001006425].

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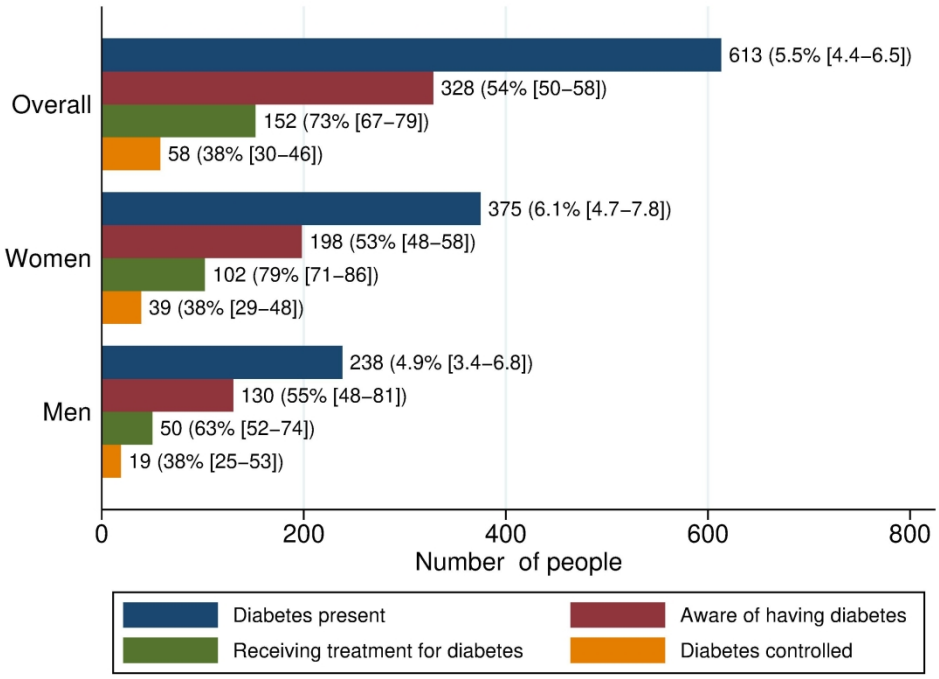
Figure 1. Diabetes cascade of care in six sub-Saharan African countries, overall and stratified by gender

Estimates given as counts and proportions with 95% confidence intervals and proportions calculated as percentages of eligible individuals in previous stage. Numbers for treatment prevalence and control exclude Soweto as these data were not collected at that site and calculations of proportions at these stages therefore also exclude this site from the denominator. Data on diabetes control were missing for a further 17 participants.



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Supplemental material

Supplemental Table S1. Diabetes care cascade by study site

Supplemental Table S2. Factors associated with odds of having diabetes across three sub-Saharan African sites with high HIV prevalence (Agincourt, Dikgale & Nairobi)

Supplemental Table S3. Factors associated with odds of having diabetes across two sub-Saharan African sites with low HIV prevalence (Navrongo & Nanoro)

Supplemental Table S4. Factors associated with awareness in high HIV prevalence sites (Agincourt, Dikgale, Nairobi & Soweto)

Table S1. Diabetes care cascade by study site

	Soweto				Agincourt				Dikgale				Nanoro				Navrongo				Nairobi			
	T	M	W	p	T	M	W	p	T	M	W	p	T	M	W	p	T	M	W	p	T	M	W	p
Sample size	2,027	1,025	1,002		1,465	573	892		1,168	356	812		2,084	1,045	1,039		2,014	923	1,091		1,942	886	1,056	
Diabetes present (n)	191	72	119		92	40	52		105	28	77		71	50	21		23	11	12		131	37	94	
Crude diabetes prevalence (%)	9.4 (8.2 - 11)	7.0 (5.5 - 8.8)	12 (9.9 - 14)		6.3 (5.1 - 7.6)	7.0 (5.0 - 9.4)	5.8 (4.4 - 7.6)		9.0 (7.4 - 11)	7.9 (5.3 - 11)	9.5 (7.6 - 12)		3.4 (2.7 - 4.3)	4.8 (3.6 - 6.3)	2.0 (1.3 - 3.1)		1.1 (0.7 - 1.7)	1.2 (0.6 - 2.1)	1.1 (0.6 - 1.9)		6.8 (5.7 - 8.0)	4.2 (3.0 - 5.7)	8.9 (7.3 - 11)	
Age-adjusted diabetes prevalence (%)	9.0 (7.8 - 10)	6.3 (4.9 - 7.9)	12 (9.7 - 14)	<0.001	5.3 (4.1 - 6.4)	5.7 (4.0 - 8.1)	5.0 (3.6 - 6.8)	0.559	7.4 (6.0 - 8.9)	7.2 (4.6 - 11)	7.5 (5.8 - 9.6)	0.857	3.3 (2.5 - 4.0)	4.7 (3.5 - 6.3)	1.8 (1.1 - 2.8)	<0.001	1.3 (0.7 - 1.9)	1.3 (0.6 - 2.4)	1.3 (0.6 - 2.5)	>0.99	6.7 (5.6 - 7.8)	4.1 (2.9 - 5.7)	9.1 (7.3 - 11)	<0.001
Aware of having diabetes (n)	120	51	69		55	22	33		61	16	45		18	16	2		15	8	7		59	17	42	
Aware of having diabetes (%)	63 (56 - 70)	71 (59 - 81)	58 (49 - 67)	0.075	60 (49 - 70)	55 (39 - 71)	64 (50 - 76)	0.412	58 (48 - 68)	57 (37 - 76)	58 (47 - 70)	0.905	25 (16 - 37)	32 (20 - 47)	9.5 (1.2 - 30)	0.047	65 (43 - 84)	73 (39 - 94)	58 (28 - 85)	0.468	45 (36 - 54)	46 (30 - 63)	45 (34 - 55)	0.895
Reporting treatment for diabetes (n)	NA	NA	NA		41	18	23		54	11	43		4	3	1		7	4	3		46	14	32	
Reporting treatment for diabetes (%)	NA	NA	NA		75 (61 - 85)	82 (60 - 95)	70 (51 - 84)	0.312	89 (78 - 95)	69 (41 - 89)	96 (85 - 100)	0.004	22 (6.4 - 48)	19 (4 - 46)	50 (1.3 - 99)	0.316	47 (21 - 73)	50 (16 - 84)	43 (9.9 - 82)	0.782	78 (65 - 88)	82 (57 - 96)	76 (61 - 88)	0.605
Diabetes controlled (n)	NA	NA	NA		13	5	8		25	4	21		2	1	1		4	3	1		14	6	8	
Diabetes controlled (%)	NA	NA	NA		32 (18 - 48)	28 (9.7 - 54)	35 (16 - 57)	0.632	46 (33 - 60)	36 (11 - 69)	49 (33 - 65)	0.461	50 (6.8 - 93)	33 (0.8 - 91)	100 (-)	0.681	57 (18 - 90)	75 (19 - 99)	33 (0.8 - 91)	0.270	30 (18 - 46)	43 (18 - 71)	25 (12 - 43)	0.226

T: total, M:men, W:women; prevalences are given as estimates and 95% confidence intervals. p value for men vs women and calculated using chi-squared or Fisher's exact test. NA-not applicable as these data were not collected

Table S2. Factors associated with odds of having diabetes across three sub-Saharan African sites with high HIV prevalence (Agincourt, Dikgale & Nairobi)[1]

	Odds ratio	95% confidence interval	p value
Age	1.1	1.0-1.1	<0.001
Sex			
Women	reference		
Men	0.8	0.5-1.2	0.209
Marital status			
Currently married or cohabitating	reference		
Never marrried or cohabitating	1.2	0.8-1.8	0.369
Previously married	1.0	0.8-1.4	0.913
Educational attainment			
No formal education	reference		
Primary education	1.5	1.0-2.2	0.074
Secondary education	1.2	0.8-1.9	0.443
Tertiary education	1.2	0.6-2.6	0.602
Employment status			
Unemployed	reference		
Employed	1.2	0.9-1.6	0.188
Smoking status			
No history of smoking	reference		
Current smoker	0.6	0.4-1.1	0.084
History of hypertension			
No	reference		
Yes	2.0	1.5-2.6	<0.001
HIV status			
Negative	reference		
Positive	0.5	0.4-0.8	0.001
Family history of diabetes			
No	reference		
Yes	3.6	2.8-4.7	<0.001
Physical activity categories			
Absent	reference		
Insufficient	1.4	0.7-3.0	0.333
Sufficient	1.1	0.6-2.0	0.729
Hip circumference	1.0	1.0-1.0	0.001
Visceral fat	1.2	1.1-1.2	<0.001
Subcutaneous fat	1.3	1.1-1.4	<0.001

[1]3929 participants were included in the analysis

Table S3. Factors associated with odds of having diabetes across two sub-Saharan African sites with low HIV prevalence (Navrongo & Nanoro)[1]

	Odds ratio	95% confidence interval	p value
Age	1.0	1.0-1.1	0.181
Sex			
Women	reference		
Men	1.9	1.1-3.3	0.033
Marital status			
Currently married or cohabitating	reference		
Never married or cohabitating	1.8	0.2-14.2	0.580
Previously married	1.2	0.6-2.3	0.682
Educational attainment			
No formal education	reference		
Primary education	0.5	0.2-1.2	0.117
Secondary education	0.9	0.4-2.5	0.906
Tertiary education	3.7	1.0-13.9	0.051
Employment status			
Unemployed	reference		
Employed	1.8	0.8-3.9	0.134
Smoking status			
No history of smoking	reference		
Current smoker	0.9	0.3-2.6	0.793
History of hypertension			
No	reference		
Yes	1.2	0.7-2.1	0.498
HIV status			
Negative	reference		
Positive	1.7	0.2-13.5	0.628
Family history of diabetes			
No	reference		
Yes	10.4	4.3-25.4	<0.001
Physical activity categories			
Absent	reference		
Insufficient	0.5	0.1-1.7	0.232
Sufficient	0.5	0.3-0.8	0.009
Hip circumference	1.0	1.0-1.1	0.023
Visceral fat	1.2	1.0-1.4	0.140
Subcutaneous fat	1.1	0.7-1.9	0.724

[1]3496 participants were included in the analysis

Table S4. Factors associated with awareness in high HIV prevalence sites (Agincourt, Dikgale, Nairobi & Soweto)[1]

	Odds Ratio	95% confidence interval	p value
Age	1.0	1.0-1.1	0.094
Sex			
Women	reference		
Men	1.0	0.6-1.6	0.849
Marital status			
Currently married or cohabitating	reference		
Never married or cohabitating	1.0	0.5-2.1	0.933
Previously married	0.9	0.5-1.4	0.600
Educational attainment			
No formal education	reference		
Primary education	1.1	0.5-2.3	0.858
Secondary education	1.4	0.7-3.2	0.370
Tertiary education	1.2	0.4-3.9	0.790
Employment status			
Unemployed	reference		
Employed	0.8	0.5-1.2	0.204
History of hypertension			
No	reference		
Yes	1.9	1.2-2.9	0.008
HIV status			
Negative	reference		
Positive	2.1	1.1-4.0	0.034
Body mass index	1.0	0.9-1.0	0.170

[1]397 participants were included in the analysis

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	3
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	3-4
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	6-7
Objectives	3	State specific objectives, including any prespecified hypotheses	7
Methods			
Study design	4	Present key elements of study design early in the paper	7-8
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	7-8
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	7-8
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	8-10
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	8-10
Bias	9	Describe any efforts to address potential sources of bias	10-11
Study size	10	Explain how the study size was arrived at	7-8
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	10-12
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	10-12
		(*b*) Describe any methods used to examine subgroups and interactions	10-12
		(*c*) Explain how missing data were addressed	12
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	n/a
		(*e*) Describe any sensitivity analyses	11-12
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	12,15
		(b) Give reasons for non-participation at each stage	15
		(c) Consider use of a flow diagram	
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	12-14
		(b) Indicate number of participants with missing data for each variable of interest	13-15, 17, 18
Outcome data	15*	Report numbers of outcome events or summary measures	15

Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	16
		(*b*) Report category boundaries when continuous variables were categorized	n/a
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	n/a
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	16
Discussion			
Key results	18	Summarise key results with reference to study objectives	18
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	20-21
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	18-22
Generalisability	21	Discuss the generalisability (external validity) of the study results	21
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	23-24

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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Diabetes care cascade and associated factors in 10,700 middle-aged adults in four sub-Saharan African countries-a cross-sectional study

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Full title: Diabetes care cascade and associated factors in 10,700 middle-aged adults in four sub-Saharan African countries - a cross-sectional study

Running title: Diabetes care cascade in sub-Saharan Africa

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Abstract

Objectives: We investigated progression through the care cascade and associated factors for people with diabetes in sub-Saharan Africa to identify attrition stages that may be most appropriate for targeted intervention.

Design: Cross-sectional study.

Setting: Community-based study in four sub-Saharan African countries.

Participants: 10 700 individuals, aged 40-60 years.

Primary and secondary outcome measures: The primary outcome measure was the diabetes cascade of care defined as the age-adjusted diabetes prevalence (self-report of diabetes, fasting plasma glucose [FPG]≥7 mmol/l or random plasma glucose≥11.1 mmol/l) and proportions of those who reported awareness of having diabetes, ever having received treatment for diabetes and those who achieved glycaemic control (FPG<7.2 mmol/l). Secondary outcome measures were factors associated with having diabetes and being aware of the diagnosis.

Results: Diabetes prevalence was 5.5% (95%CI 4.4-6.5%). Approximately half of those with diabetes were aware (54%; 95%CI 50-58%); 73% (95%CI 67-79%) of aware individuals reported ever having received treatment. However, only 38% (95%CI 30-46%) of those ever having received treatment were adequately controlled. Increasing age (OR 1.1; 95%CI 1.0-1.1), urban residence (OR 2.3; 95%CI 1.6-3.5), hypertension (OR 1.9; 95%CI 1.5-2.4), family history of diabetes (OR 3.9;

95%CI 3.0-5.1), and measures of central adiposity were associated with higher odds of having diabetes. Increasing age (OR 1.1; 95%CI 1.0-1.1), semi-rural residence (OR 2.5; 95%CI 1.1-5.7), secondary education (OR 2.4; 95%CI 1.2-4.9), hypertension (OR 1.6; 95%CI 1.0-2.4), and known HIV positivity (OR 2.3; 95%CI 1.2-4.4) were associated with greater likelihood of awareness of having diabetes.

Conclusions: There is attrition at each stage of the diabetes care cascade in sub-Saharan Africa. Public health strategies should target improving diagnosis in high-risk individuals and intensifying therapy in individuals treated for diabetes.

Keywords: diabetes mellitus, sub-Saharan Africa

Strength and limitations of this study

- We present harmonised primary data on the diabetes care cascade from multiple countries in sub-Saharan Africa
- Our study included over 10,000 participants from eastern, western and southern Africa
- We did not perform glucose tolerance testing and therefore may not have identified individuals who met criteria for diabetes diagnosis only after a glucose challenge
- Glycaemic control was assessed using fasting plasma glucose which provides a point evaluation and may not be reflective of control over a longer period of time

INTRODUCTION

Diabetes prevalence in adults in sub-Saharan Africa (SSA) is projected to increase from 23.6 million in 2021 to 54.9 million people in 2045.[1] Inadequate control of blood sugar and other cardiovascular risk factors will impose an unsustainable burden of diabetes-related complications on already constrained regional health care systems. Existing data suggest that outcomes in individuals in SSA with diabetes are currently suboptimal with over 300,000 diabetes-related deaths before the age of 60 years in 2021,[1] highlighting the need to improve clinical care. Optimisation of diabetes management is contingent on numerous factors including the diagnosis of diabetes, appropriate escalation of therapy and patient adherence to therapeutic interventions, but effective strategies to improve diabetes management in SSA are hampered by a lack of knowledge about the extent of the deficiencies in this care continuum.

The cascade of care model, frequently used to identify deficits in HIV care, may be applied to diabetes to identify opportunities for improved outcomes.[2-4] The elements of the cascade, namely prevalence, awareness, treatment and control reflect aspects of the health care system, including effectiveness of prevention and detection strategies and the ability to implement and escalate therapy as necessary. On an individual level, diabetes awareness in particular is key to the adherence to lifestyle modification and medication that underpin glycaemic control. Evaluation of the diabetes care cascade allows policy makers to assess how well the health care system manages patients with diabetes and to identify areas for targeted interventions, particularly important in the resource-constrained lower and middle-income countries of SSA.

Despite the benefits of establishing the diabetes care cascade, there is a paucity of primary data on it in SSA. Studies have often been limited to diabetes prevalence and awareness and conducted in hospital-based populations, introducing selection bias, while multi-country studies that have reported on the entire cascade have meta-analysed data from heterogeneous studies with methodological differences in determining each cascade stage. We aimed to evaluate the diabetes cascade of care in four SSA countries, using harmonised data collected across six sites, and performed exploratory analyses of the cascade stratified by sex and study site. We further investigated factors associated with the likelihood of having diabetes and being aware of a diagnosis of diabetes, the first two steps in the cascade.

METHODS

Study Setting and Participants

The AWI-Gen study and participating sites have been described in detail elsewhere.[5,6] In brief, 10,700 individuals were recruited from six sites in SSA in a community-based, cross-sectional study conducted between August 2013 and August 2016. Individuals were eligible for inclusion if they were aged 40-60 years and resided permanently in the study sites. Exclusion criteria were pregnancy and, given that one of the broader programme project objectives was to investigate genomic determinants of cardiometabolic disease, being closely related to an existing participant and recent immigration into the study site. We selected individuals aged 40-60 years as this is a peak time for the development of cardiometabolic disease. Three of the study sites were in South Africa (Soweto, Agincourt and Dikgale), one was in Kenya (Nairobi), one in Ghana (Navrongo) and

one in Burkina Faso (Nanoro). Participants were therefore included from southern, eastern and western Africa. The selected sites were also on a continuum of urbanisation: Nairobi and Soweto were urban sites, Agincourt and Dikgale were semi-rural and Nanoro and Navrongo were rural.

With the exception of Soweto, each study site is home to a Health and socio-Demographic Surveillance System (HDSS) which enumerates all residents within the HDSS on a regular basis, ensuring a well-defined population sampling frame. In Nairobi, Agincourt, Navrongo and Nanoro, individuals were randomly sampled from the sampling frame, while in Dikgale, a convenience sampling strategy was employed. In Soweto, 700 women who were participants in the Study of Women Entering an Endocrine Transition (SWEET) study[7] and caregivers of the Birth to Twenty+ cohort[8] were recruited. Additional female and all male participants were randomly recruited, using a sampling frame which covered the Soweto region. Where necessary, there was oversampling to ensure equal numbers of women and men.

Patient and public involvement

Prior to the initiation of the AWI-Gen study, an extensive process of community engagement was conducted. This included meetings with civic and traditional leadership structures, household visits and group information sessions to discuss planned research activities. Study results were delivered annually to study participants, communities and community leaders.

Data Collection and Definitions

Data were collected by study staff trained on standardised protocols. Sociodemographic data and personal and family medical history were self-reported. Additionally, individuals were considered to have hypertension if the mean systolic blood pressure of the latter two of three readings at the study visit ≥140 mmHg or the mean diastolic pressure ≥90 mmHg (Omron M6, Omron, Kyoto, Japan).[9] Individuals were classified as HIV positive if they reported a previous diagnosis of HIV or if they tested positive on the rapid HIV tests that were offered to participants in South Africa and Kenya (MD HIV 1/2 test [Medical Diagnostech, Cape Town, South Africa]; One Step anti-HIV1+2 rapid screen test [InTec, Xiamen, China]; Determine rapid test kit [Abbot Pharmaceuticals, Chicago, USA]). Rapid HIV tests were not offered in Ghana and Burkina Faso due to the low prevalence of HIV in those countries; individuals in these sites who did not know their HIV status were classified as HIV negative. Physical activity was assessed using the Global Physical Activity Questionnaire and occupational, leisure time and travel-related physical activity variables from this questionnaire were summed to give the total moderate-vigorous intensity physical activity (MVPA) in minutes per week. Individuals were classified as having no MVPA (0 minutes/week), insufficient MVPA (1-150 minutes/week) or sufficient MVPA (≥150 minutes/week).[10]

Standing height was measured with the participant barefoot or in light socks, using a Harpenden digital stadiometer (Holtain, Wales, UK). Weight was measured with the participant in light clothing, using a digital Physician Large Dial 200 kg capacity scale (Kendon Medical, South Africa) and body mass index was calculated as weight in kg divided by height in metres squared. Using a stretch-resistant measuring tape

(SECA, Hamburg, Germany), hip circumference, as a measure of gluteofemoral fat, was measured around the most protruding part of the buttocks.

Visceral and subcutaneous adipose tissue, direct measures of central adiposity associated with insulin resistance, were measured using abdominal ultrasound (LOGIQ e ultrasound system [GE Healthcare, CT, USA]). Study staff from all sites were centrally trained in Johannesburg, South Africa to perform the abdominal ultrasounds. Visceral adipose thickness was determined by the thickness of the fat pad between the anterior spine and peritoneal layer at end expiration, while subcutaneous adipose thickness was the thickness of the fat pad between the skin and the outer edge of the linea alba.

Venous blood was collected at study visits in potassium oxalate/sodium fluoride tubes and centrifuged immediately after collection, with the supernatant plasma stored at -80°C until analysis, according to a detailed sample processing protocol provided to all sites. Analyses for glucose were all performed at a central site, using colorimetric methods, on the Randox Plus clinical chemistry analyser (Randox, UK) with a range of 0.36–35 mmol/l and coefficient of variation<2.3%.

Diabetes was defined as a previous diagnosis of diabetes by a health care provider, ever having received treatment for diabetes, or fasting plasma glucose ≥7 mmol/l or random plasma glucose ≥11.1 mmol/l [11,12] on the sample taken during the study visit. Samples were considered random if a participant had not fasted overnight or fasting status could not be confirmed. Participants were considered to be aware of a diagnosis of diabetes if they reported ever having been told by a health professional

that they had diabetes and were considered to have been treated for diabetes if they reported ever having received treatment for diabetes (dietary advice and/or glucose lowering agents) from a health care professional. Individuals were considered to have their diabetes controlled if fasting glucose was <7.2 mmol/l.[11]

Statistical Analysis

Categorical participant characteristics of marital status, highest level of education, current smoking, known hypertension, known HIV positivity, family history of diabetes and physical activity category were described using frequencies and percentages, while medians and interquartile ranges (IQR) were used to describe continuous characteristics of age, body mass index, hip circumference, visceral fat and subcutaneous fat. The Mann-Whitney U, chi-squared and Fisher's exact tests were used to compare continuous and categorical variables respectively between groups defined by sex to investigate sex-related differences in potential determinants and groups defined by data missingness status to evaluate for bias between those who were included and those who were excluded from the analysis due to missing data.

Age-adjusted diabetes prevalence was determined using the United Nations African population distribution[13] as the reference population structure. The proportion of those aware of having diabetes was calculated as a percentage of those with diabetes and similarly, the proportion of those ever receiving treatment for diabetes was calculated as a percentage of those aware of having diabetes; the proportion of those who had their diabetes controlled was calculated as a percentage of those who reported ever receiving treatment. The method for interval estimation described

by Tiwari et al.[14] was used to determine the 95% confidence intervals. The Soweto site was excluded from the latter two stages of the cascade as the 'ever receiving treatment' variable was not collected.

Multivariable logistic regression was used to assess the relationship between the odds of having diabetes and sociodemographic and clinical characteristics including urbanicity. Independent variables for inclusion in the logistic regression were selected based on previous research.[15,16] The Soweto site did not collect data on family history of diabetes and was therefore not included in this model, as family history of diabetes has been demonstrated in other settings to be strongly associated with higher odds of having the condition. Additional multivariable logistic regression models were also fit, using data from all sites, to investigate associations with awareness of a diagnosis of diabetes. In the model investigating associations with odds of having diabetes, we included visceral and subcutaneous fat as direct assessments of central obesity and hip circumference as a measure of gluteofemoral fat. In the model investigating associations with awareness, we used body mass index as the measure of obesity as we thought awareness was more likely to be associated with a global assessment of obesity rather than individual fat depots. We were underpowered to assess associations with diabetes treatment and control.

Sensitivity analyses were conducted in which associations with having diabetes and awareness of a diagnosis of diabetes were explored in analyses stratified by HIV prevalence, with the South African sites and Nairobi classified as high prevalence sites and Navrongo and Nanoro classified as low prevalence sites.

Missing data were handled using pairwise deletion. Analyses were conducted using Stata v16 (StataCorp, USA).

RESULTS

Sample Characteristics

The characteristics of the 10,700 study participants are shown in Supplemental Table S1. There were 5,892 women (55%), with a median age of 50 years (IQR 45-55). There was some inter-site variation in sociodemographic variables - while most participants in the urban and semi-rural sites had some formal education, between 70-80% of participants in the rural sites did not. Smoking prevalence ranged between 6% and 30% overall, with prevalence several fold higher in men than in women in all sites. There was a high prevalence of chronic disease with 3,755 (37%) participants having hypertension and 1,310 (12%) known as being HIV positive, although inter-site variation was evident, with HIV prevalence being low, for example, in Nanoro and Navrongo. Family history of diabetes was highest in the urban and semi-rural areas. Anthropometric measures of obesity and subcutaneous fat were higher in women in urban and semi-urban areas, while there were no clear sex differences in Nanoro or Navrongo. Visceral fat was generally similar in both sexes. The majority of individuals (82%) were undertaking at least 150 minutes of moderate to vigorous physical activity weekly.

Missing Outcome Data

No participants had missing data on the diabetes status outcome, while 31 individuals had missing data on the awareness outcome and were slightly older (median age 54 vs 52 years; p=0.04), less likely to be employed (32 vs 64%; p<0.01) and had a different marital status distribution (p<0.01) than those who were not missing these data.

Diabetes Cascade of Care

The diabetes cascade of care is shown in Figure 1. The age-adjusted prevalence of diabetes in study participants was 5.5% (95%CI 4.4-6.5%) and was significantly higher in women (6.1% vs 4.9%; p<0.01). Prevalence varied by site, with highest prevalence in the urban site of Soweto (9.0%; 95%CI 7.8-10%) and the lowest in rural Navrongo (1.3%; 95%CI 0.7-1.9%) (Supplemental Table S2). Diabetes prevalence was higher in women than men in Soweto and Nairobi (Soweto: 12% vs 6.3%, p<0.01; Nairobi: 9.1% vs 4.1%, p<0.01) while in Nanoro, the prevalence was higher in men (1.8% vs 4.7%, p<0.01).

Overall, just over half of the 613 individuals with diabetes were aware of their condition (54%; 95%CI 50-58%), with the highest awareness in Navrongo (65%; 95%CI 43-84%) and the lowest in Nanoro (25%; 95%CI 16-37%), although confidence intervals across the sites were wide and overlapping. Nearly 75% of individuals aware of having diabetes reported ever receiving treatment, but only 38% (95%CI 30-41%) were adequately controlled. More women reported ever being treated for diabetes (p=0.01), but there were no sex differences in participants achieving control (p=0.98).

In logistic regression models, increasing age (odds ratio [OR] 1.1; 95%CI 1.0-1.1; p<0.01) and urban residence (OR 2.3; 95%CI 1.6-3.5; p<0.01) were associated with higher odds of having diabetes (Table 1). Hypertension was also associated with having diabetes (OR 1.9; 95%CI 1.5-2.4; p<0.01), as was family history of diabetes (OR 3.9; 95%CI 3.0-5.1; p<0.01); conversely, known HIV positivity was associated with lower odds of diabetes (OR 0.6; 95%CI 0.4-0.9; p<0.01). Visceral and subcutaneous fat were also associated with higher odds, while there was a marginal negative association with hip circumference (Table 1).

Similar associations were evident in sensitivity analyses restricted to sites with high HIV prevalence (Supplemental Table S3). However, only family history remained significantly associated with diabetes in low HIV prevalence settings, although previously unobserved associations with male sex and physical activity emerged (Supplemental Table S4). These analyses were however limited by the low prevalence of diabetes in these settings which meant they were underpowered.

Increasing age (OR 1.1; 95%CI 1.0-1.1; p=0.02), semi-rural environment (OR 2.5; 95%CI 1.1-5.7; p=0.02) and secondary education (OR 2.4; 95%CI 1.2-4.9; p=0.02) were all associated with greater likelihood of awareness of diabetes, as were the chronic conditions of hypertension (OR 1.6; 95%CI 1.0-2.4; p=0.04) and known HIV positivity (OR 2.3; 95%CI 1.2-4.4; p=0.02) (Table 2). In sensitivity analyses in high HIV prevalence sites, only hypertension and known HIV positivity remained associated with higher awareness of diabetes (Supplemental Table S5). The sample size in low HIV prevalence sites was too small to perform meaningful analyses.

Table 1. Factors associated with odds of having diabetes in five sub-Saharan African sites (Agincourt, Dikgale, Nairobi, Nanoro & Navrongo)[1]

	Odds Ratio	95% confidence interval	p value
Age	1.1	1.0-1.1	<0.01
Sex			
Women	reference		
Men	1.1	0.8-1.5	0.65
Location			
Rural	reference		
Semi-rural	1.5	1.0-2.3	0.08
Urban	2.3	1.6-3.5	<0.01
Marital status			
Currently married or cohabitating	reference		
Never married or cohabitating	1.4	0.9-2.0	0.15
Previously married	1.0	0.8-1.3	0.99
Educational attainment			
No formal education	reference		
Primary education	1.2	0.9-1.7	0.29
Secondary education	1.0	0.7-1.5	0.84
Tertiary education	1.4	0.7-2.6	0.37
Employment status			
Unemployed	reference		
Employed	1.1	0.8-1.5	0.48
Smoking status			
No history of smoking	reference		
Current smoker	0.7	0.4-1.1	0.15
History of hypertension			
No	reference		
Yes	1.9	1.5-2.4	<0.01
Known HIV positivity			
No	reference		
Yes	0.6	0.4-0.9	0.01
Family history of diabetes			
No	reference		
Yes	3.9	3.0-5.1	<0.01
Physical activity categories			
Absent	reference		
Insufficient	0.9	0.5-1.5	0.61
Sufficient	0.7	0.5-1.0	0.08
Hip circumference	1.0	1.0-1.0	0.04
Visceral fat	1.2	1.1-1.2	<0.01
Subcutaneous fat	1.3	1.1-1.4	<0.01

[1]7,425 participants were included in the analysis. Participants from the Soweto site were excluded as data on family history were not collected. Age was entered as a continuous variable

Table 2. Factors associated with awareness of diabetes in six sub-Saharan African sites (Agincourt, Dikgale, Nairobi, Nanoro, Navrongo & Soweto)[1]

	Odds Ratio	95% confidence interval	p value
Age	1.0	1.0-1.1	0.02
Sex			
Women	reference		
Men	1.1	0.7-1.8	0.59
Location			
Rural	reference		
Semi-rural	2.5	1.1-5.7	0.02
Urban	1.5	0.7-3.1	0.34
Marital status			
Currently married or cohabitating	reference		
Never married or cohabitating	0.9	0.4-2.0	0.84
Previously married	1.0	0.6-1.7	0.86
Educational attainment			
No formal education	reference		
Primary education	1.8	0.9-3.5	0.09
Secondary education	2.4	1.2-4.9	0.02
Tertiary education	2.1	0.7-6.1	0.17
Employment status			
Unemployed	reference		
Employed	0.8	0.5-1.3	0.45
History of hypertension			
No			
Yes	1.6	1.0-2.4	0.04
Known HIV positivity			
No	reference		
Yes	2.3	1.2-4.4	0.02
Body mass index	1.0	1.0-1.0	0.97

[1]472 participants were included in the analysis. Age and body mass index were entered as continuous variables.

DISCUSSION

In this multi-country study of the diabetes care cascade in SSA, we demonstrate attrition at each stage of the cascade with just over half of those with diabetes being aware of their condition and only approximately a third of those who reported ever receiving treatment achieving optimal glycaemic control. We also report sociodemographic and clinical factors associated with increased odds of having diabetes including older age, urban residence and having hypertension and factors associated with awareness of having diabetes which included increasing age, semi-

rural environment, secondary education and having hypertension or known HIV positivity.

Our prevalence estimate of 5.5% is similar to the 2019 International Diabetes Federation (IDF) estimate for SSA of 4.7% in adults aged 20-79 years.[1] A sub-regional meta-analysis from western Africa revealed a lower prevalence (4.0% in urban adults and 2.6% in rural adults),[17] in keeping with our study where prevalence in the western African sites was two to three times lower than in the southern and eastern African sites. Factors in our study associated with higher odds of having diabetes, such as increasing age and urban residence, have been previously reported, with the western African meta-analysis reporting over a threefold increase in prevalence in people over 50 years[17] and Werfalli et al. reporting a prevalence of 20% in people living in urban areas vs 7.9% in those in rural areas.[18] Our findings of associations with family history of diabetes, hypertension and adiposity support results from other country-level meta-analyses in Africa.[19,20] We also noted lower odds of having diabetes in individuals with known HIV in keeping with other studies that have identified lower prevalence of cardiometabolic risk factors in individuals with HIV in SSA.[21,22]

While our estimate of the prevalence of diabetes unawareness of 47% was broadly similar to the 2019 IDF estimate of the prevalence of undiagnosed diabetes of 60% in SSA,[1] it did contrast sharply with other studies. A meta-analysis of 23 studies from across Africa estimated a much lower pooled prevalence of undiagnosed diabetes of just under 4%.[23] There was however significant heterogeneity in the included studies and the majority of the data originated from a single country, which

may not be representative of other countries in the region. This itself differed considerably from data from 12 nationally representative surveys in SSA in which 73% of those with diabetes were unaware of their condition, with factors similar to our study, namely older age and higher level of educational attainment, associated with awareness.[24] Our findings also suggest that those with chronic diseases such as HIV and hypertension may be more aware of having diabetes, which may be due to increased contact with the health care system.[25]

In a study reporting data from 15 sub-Saharan African countries, approximately 40% of adults with diabetes received glucose-lowering medication, while approximately 25% received counselling on diet, exercise or weight loss.[2] These proportions are lower than ours which may be due to the difference in denominators - we used a denominator of individuals aware of having diabetes rather than all those with diabetes. In another study reporting data from 12 sub-Saharan African countries, just over 30% of those with diabetes were aware of their condition, with a similar percentage ever having received lifestyle advice or currently receiving diabetes medication and just over 20% achieving control. [3] While this study also used a fixed denominator of the number of people with diabetes, the results support our finding that there is not a major fall-off between the stages of awareness and treatment and the most significant deficits are at the stages of awareness of having diabetes i.e., diagnosis and achieving glycaemic control. Of note, this study used a more liberal definition of glycaemic control than our study (FPG <10.1 mmol/l or HbA1c <8% in the single study in which it was available) and may have identified a more drastic control deficit if a threshold for glycaemic control similar to ours had been used. A country-level meta-analysis of 22 studies from Ethiopia suggested a

similar degree of glycaemic control as our study, with approximately a third of those included achieving glycaemic targets, regardless of whether these were assessed using fasting plasma glucose or HbA_{1c}.[26]

We describe, to our knowledge, the first study in SSA in which harmonised primary data on the diabetes care cascade have been collected from multiple countries. Previous multi-country research in SSA on this subject has relied on systematic reviews and meta-analyses and has therefore been limited by the methodological heterogeneity of the constituent studies, including the use of different biomarkers to define diabetes. In our work, data were collected in a standardised manner and in addition to self-report, we used venous blood samples, analysed at a single laboratory, to ascertain biochemical evidence of diabetes. Our study also included over 10,000 men and women from three sub-regions of SSA.

Our study does have limitations. We did not distinguish between type 1 and type 2 diabetes and the care cascade and associated factors may differ between these two conditions. While we used accepted and convenient diagnostic criteria for diabetes, we may have underestimated the prevalence of diabetes as we did not assess glucose tolerance and may therefore have excluded those who met the criteria for diabetes only after a glucose challenge, which may be particularly important in populations of African descent. Both oral glucose tolerance tests and HbA_{1c}, appear to classify more African-ancestry individuals as having diabetes than FPG alone [27, 28] and use of either of these criteria may have increased diabetes prevalence in our study. Our research was conducted in HDSS sites and among a research cohort in Soweto, populations which may not be nationally representative. Indeed, individuals

in these sites may have been told they had diabetes while taking part in previous studies, making the proportion of individuals with diabetes who know they have the condition higher than in the general population. We also used self-report rather than clinical records to determine ever receiving diabetes treatment. Fasting plasma glucose was used to assess diabetes control and this provides an evaluation only at a single point in time and may be subject to more analytic variability than HbA_{1c}, which has largely supplanted it in clinical use in well-resourced environments. Several large scale epidemiological studies have however used plasma glucose measures to assess glycaemic control.[2,3]

Despite these limitations, our study provides valuable information on the burden of diabetes in SSA and the deficiencies which need to be addressed to improve outcomes. In areas where diabetes prevalence is low, primordial prevention strategies should be employed to reduce the likelihood of developing risk factors such as obesity, with particular focus on higher risk urban environments. Screening of at-risk populations needs to be enhanced and the low percentage of individuals attaining satisfactory glycaemic control suggests that more aggressive, treat to target strategies need to be promoted among health care workers, although we acknowledge this may be limited by drug availability in many parts of the continent.

Additional work is necessary to understand whether our findings are applicable to other SSA countries and sub-regions at different stages of the epidemiological transition and with variable access to health care. It is also essential to understand key determinants of ever receiving diabetes treatment and control, which we were underpowered to investigate, and care cascades for other important vascular risk

factors in people with diabetes, such as elevated blood pressure and dyslipidaemia. Identification of the points in each of these care cascades at which significant attrition is occurring will assist public health officials in developing appropriate interventions to reduce diabetes-related morbidity and mortality.

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ANW and MR had full access to all the data in the study and take responsibility for the integrity of the data. IM performed the data analysis and takes responsibility for its accuracy. All authors consent to the publication of this manuscript and agree to be accountable for all aspects of this work.

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Data statement: De-identified individual participant data from the AWI-Gen study are available from the European Genome-Phenome Archive (EGA) at study number EGA00001002482 [https://ega459 archive.org/datasets/EGAD00001006425].

Ethics Approval

Written informed consent was provided by participants in their local languages. Ethical approval for the AWI-Gen study was provided by the Human Research Ethics Committee (Medical) of the University of the Witwatersrand (M121029, M170880). Each of the HDSS centres also obtained ethical approval according to their respective institutional and country-specific regulations.

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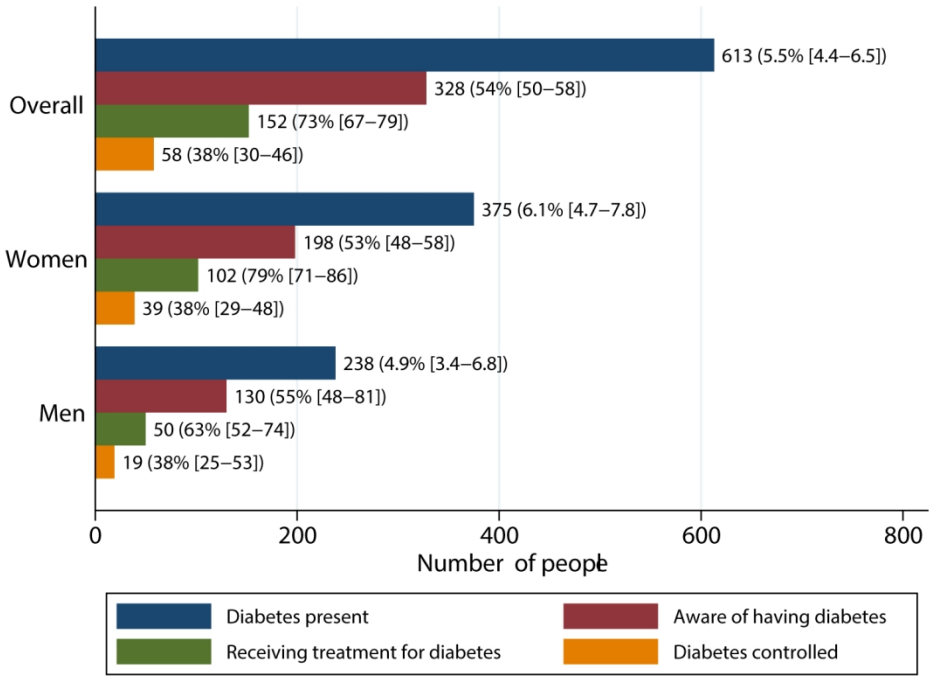
Figure 1. Diabetes cascade of care in six sub-Saharan African countries, overall and stratified by gender

Estimates given as counts and proportions with 95% confidence intervals and proportions calculated as percentages of eligible individuals in previous stage. Estimates for ever receiving treatment and achieving glycaemic control (calculated as percentage of those who ever received treatment) exclude Soweto as the treatment variable was not collected at that site. Data on diabetes control were missing for a further 17 participants.



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Supplemental material

Supplemental Table S1. Demographic and clinical characteristics of 10,700 study participants in six sub-Saharan African sites

Supplemental Table S2. Diabetes care cascade by study site

Supplemental Table S3. Factors associated with odds of having diabetes across three sub-Saharan African sites with high HIV prevalence (Agincourt, Dikgale & Nairobi)

Supplemental Table S4. Factors associated with odds of having diabetes across two sub-Saharan African sites with low HIV prevalence (Navrongo & Nanoro)

Supplemental Table S5. Factors associated with awareness in high HIV prevalence sites (Agincourt, Dikgale, Nairobi & Soweto)

Table S1. Demographic and clinical characteristics of 10,700 study participants in six sub-Saharan African sites

	Soweto			Agincourt			Dikgale			Nanoro			Navrongo			Nairobi			Overall		
	Men	Women	Overall	Men	Women	Overall	Men	Women	Overall	Men	Women	Overall	Men	Women	Overall	Men	Women	Overall	Men	Women	Overall
	n=1,025 51%	n=1,002 49%	n=2,027	n=573 39%	n=892 61%	n=1,465	n=356 31%	n=812 69%	n=1,168	n=1,045 50%	n=1,039 50%	n=2,084	n=923 46%	n=1,091 54%	n=2,014	n=886 46%	n=1,056 54%	n=1,942	n=4,808 45%	n=5,892 55%	n=10,700
Age (years)	49 (44-55)	49 (44-54)	49 (44-54)	51 (45-56)	51 (46-56)	51 (46-56)	50 (45-55)	51 (46-56)	51 (45-55)	50 (44-55)	50 (45-54)	50 (45-55)	50 (46-55)	52 (47-56)	51 (46-56)	48 (44-53)	48 (44-52)	48 (44-53)	50 (45-55)	50 (45-55)	50 (45-55)
Marital status (%)																					
Currently married/ Cohabitating	570 (56)	266 (27)	836 (41)	445 (78)	537 (60)	982 (67)	178 (50)	427 (53)	605 (52)	1,021 (98)	794 (76)	1,815 (87)	787 (85)	694 (64)	1,481 (74)	808 (91)	486 (46)	1,294 (67)	3,809 (79)	3,204 (54)	7,013 (66)
Never married/ cohabitating	265 (26)	51 (5.1)	316 (16)	75 (13)	59 (6.6)	134 (9.2)	103 (29)	185 (23)	288 (25)	14 (1.3)	3 (0.3)	17 (0.8)	15 (1.6)	5 (0.5)	20 (1.0)	13 (1.5)	70 (6.6)	83 (4.3)	485 (10)	373 (6.3)	858 (8.0)
Previously married	189 (19)	347 (35)	536 (26)	53 (9.2)	296 (33)	349 (24)	75 (22)	200 (25)	275 (24)	8 (0.8)	238 (23)	246 (12)	120 (13)	392 (36)	512 (26)	65 (7.3)	499 (47)	564 (29)	510 (11)	1,972 (33)	2,482 (23)
Missing	1 (0.1)	338 (34)	339 (17)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	2 (0.2)	4 (0.4)	6 (0.3)	1 (0.1)	0 (0)	1 (0.1)	0 (0)	1 (0.1)	1 (0.1)	4 (0.1)	343 (5.8)	347 (3.2)
Highest level of education (%)																					
No formal education	8 (0.8)	2 (0.2)	10 (0.5)	23 (22)	280 (31)	403 (28)	22 (6.2)	74 (9.1)	96 (8.2)	758 (73)	960 (92)	1,718 (82)	570 (62)	843 (77)	1,413 (70)	34 (3.8)	113 (11)	147 (7.6)	1,515 (32)	2,272 (39)	3,787 (35)
Primary education	117 (11)	636 (64)	753 (37)	235 (41)	340 (38)	575 (39)	113 (32)	273 (34)	386 (33)	181 (17)	58 (5.6)	239 (12)	206 (22)	177 (16)	383 (19)	447 (51)	663 (63)	1,110 (57)	1,299 (27)	2,147 (36)	3,446 (32)
Secondary education	748 (73)	147 (15)	895 (44)	175 (31)	223 (25)	398 (27)	204 (57)	440 (54)	644 (55)	86 (8.2)	10 (1)	96 (4.6)	118 (13)	57 (5.2)	175 (8.7)	383 (43)	276 (26)	659 (34)	1,714 (36)	1,153 (20)	2,867 (27)
Tertiary education	152 (15)	1 (0.1)	153 (7.5)	39 (6.8)	49 (5.5)	88 (6.0)	17 (4.8)	24 (3.0)	41 (3.5)	16 (1.5)	2 (0.2)	18 (0.9)	27 (2.9)	9 (0.8)	36 (1.8)	22 (2.5)	4 (0.4)	26 (1.3)	273 (5.7)	89 (1.5)	362 (3.4)
Missing	0 (0)	216 (22)	216 (10.7)	1 (0.2)	0 (0.0)	1 (0.1)	0 (0)	1 (0.1)	1 (0.1)	4 (0.4)	9 (0.9)	13 (0.6)	2 (0.2)	5 (0.5)	7 (0.4)	0 (0)	0 (0)	0 (0)	7 (0.2)	231 (3.9)	238 (2.2)
Employed (%)	670 (65)	547 (55)	1,217 (60)	197 (34)	303 (34)	500 (34)	160 (45)	279 (34)	439 (37)	1,026 (98)	1,030 (99)	2,056 (99)	599 (65)	659 (60)	1,258 (63)	860 (97)	966 (92)	1,826 (94)	3,512 (73)	3,784 (64)	7,296 (68)
Current smoker (%)	540 (53)	49 (4.9)	589 (29)	155 (27)	3 (0.3)	158 (11)	225 (63)	25 (3.1)	250 (21)	142 (14)	0 (0)	142 (6.8)	388 (42)	21 (1.9)	409 (20)	208 (24)	27 (2.6)	235 (12)	1,658 (35)	125 (2.1)	1,783 (17)
Hypertension (%)	550 (54)	552 (55)	1102 (54)	251 (44)	517 (58)	768 (52)	116 (33)	392 (49)	508 (44)	215 (21)	127 (12)	342 (17)	227 (25)	274 (25)	501 (25)	204 (23)	319 (30)	523 (27)	1,563 (33)	2,181 (37)	3,744 (35)
Known HIV positive (%)	189 (18)	121 (12)	310 (15)	186 (33)	304 (34)	490 (33)	73 (21)	175 (22)	248 (21)	5 (0.5)	4 (0.4)	9 (0.4)	9 (1.0)	6 (0.6)	15 (0.7)	67 (7.6)	171 (16)	238 (12)	529 (11)	781 (13)	1,310 (12)

Family history of diabetes (%)	NA	NA	NA	85 (15)	161 (18)	246 (17)	53 (15)	134 (17)	187 (16)	24 (2.3)	12 (1.2)	36 (1.7)	12 (1.3)	10 (0.9)	22 (1.1)	112 (13)	213 (20)	325 (17)	286 (6.0)	530 (9.0)	816 (7.6)
Body mass index (kg/m^2)	24.2 (20.6-28.5)	32.9 (28.5-37.6)	28.4 (23-33.9)	23 (20.3-26.6)	28.6 (24.1-33.2)	26 (22.1-31.3)	20.6 (18.9-24.1)	30.1 (25.3-35.9)	26.9 (21.1-33.1)	21.1 (19.2-23.4)	19.8 (18.1-21.6)	20.4 (18.6-22.6)	20.6 (19-22.3)	21.4 (19.6-23.9)	21 (19.3-23.1)	22.2 (20-25)	26.9 (23-31.7)	24.4 (21.1-28.6)	21.7 (19.5-24.9)	25.5 (20.8-31.9)	23.2 (20.1-28.6)
Hip circumference (cm)	97.4 (90.0-105.3)	117.5 (109.0-127.0)	107.0 (95.7-118.5)	94.0 (89.0-102.0)	105.0 (97.0-113.0)	100.0 (93.0-110.0)	87.6 (83.3-94.9)	108.7 (98.5-118.9)	101.9 (90.1-114.3)	89.5 (85.6-94.9)	87.8 (83.4-92.5)	88.8 (84.5-93.7)	83.0 (79.0-88.0)	88.0 (83.0-94.0)	86.0 (81.0-91.0)	93.0 (87.4-98.9)	101.0 (94.0-110.0)	97.0 (90.0-104.6)	90.6 (85.0-98.0)	99.0 (89.0-112.0)	94.2 (86.6-105.3)
Subcutaneous fat (cm)	1.4 (0.9-2.0)	.1 (2.5-3.9)	2.2 (1.3-3.2)	1.2 (0.7-1.7)	2.2 (1.5-3.0)	1.7 (1.1-2.7)	0.8 (0.5-1.2)	2.2 (1.6-2.9)	1.7 (0.9-2.6)	0.8 (0.6-1.2)	0.9 (0.6-1.2)	0.9 (0.6 1.2)	0.7 (0.5-0.9)	1.0 (0.7-1.5)	0.8 (0.6-1.2)	1.0 (0.7-1.5)	2.0 (1.4-2.4)	1.5 (1.0-2.1)	0.9 (0.6-1.4)	1.7 (1.0-2.6)	1.2 (0.8-2.1)
Visceral fat (cm)	6.2 (5-7.8)	4.7 (3.5-5.9)	5.5 (4.2-6.9)	6.3 (5.2-7.8)	5.9 (4.2-7.3)	6.1 (4.6-7.5)	5.9 (4.7-7.4)	6.7 (4.9-8.5)	6.4 (4.9-8.2)	4.3 (3.5-5.2)	4.3 (3.6-5.1)	4.3 (3.5-5.1)	4 (3.3-4.8)	3.3 (2.8-4.1)	3.6 (3-4.5)	5 (3.9-6.3)	4.6 (3.6-5.8)	4.8 (3.7-6)	5 (3.9-6.5)	4.5 (3.4-6)	4.7 (3.6-6.2)
Physical activity categories (%)																					
Absent	63 (6.2)	167 (17)	230 (11)	106 (19)	143 (16)	249 (17)	3 (0.9)	8 (1)	11 (1.3)	227 (22)	110 (11)	337 (16)	64 (7.1)	154 (14)	218 (11)	6 (0.7)	19 (1.8)	25 (1.3)	469 (9.8)	601 (10)	1,070 (10)
Insufficient	134 (13)	283 (28)	417 (21)	21 (3.7)	58 (6.5)	79 (5.4)	16 (4.5)	27 (3.3)	134 (6.9)	37 (3.5)	34 (3.3)	71 (3.4)	35 (3.9)	59 (5.4)	94 (4.7)	41 (4.6)	93 (8.8)	134 (6.9)	284 (5.9)	554 (9.4)	838 (7.9)
Sufficient	828 (81)	552 (55)	1,380 (68)	443 (78)	686 (77)	1,129 (78)	334 (95)	776 (96)	1,780 (92)	781 (75)	895 (86)	1,676 (80)	807 (89)	874 (80)	1,681 (84)	839 (95)	941 (89)	1,780 (92)	4,032 (84)	4,724 (80)	8,756 (82)

Continuous variables are summarised as medians and interquartile ranges and categorical variables as n (%); NA-not applicable

Table S2. Diabetes care cascade by study site

	Soweto				Agincourt				Dikgale				Nanoro				Navrongo				Nairobi			
	T	M	W	p	T	M	W	p	T	M	W	p	T	M	W	p	T	M	W	p	T	M	W	p
Sample size	2,027	1,025	1,002		1,465	573	892		1,168	356	812		2,084	1,045	1,039		2,014	923	1,091		1,942	886	1,056	
Diabetes present (n)	191	72	119		92	40	52		105	28	77		71	50	21		23	11	12		131	37	94	
Crude diabetes prevalence (%)	9.4 (8.2 - 11)	7.0 (5.5 - 8.8)	12 (9.9 - 14)		6.3 (5.1 - 7.6)	7.0 (5.0 - 9.4)	5.8 (4.4 - 7.6)		9.0 (7.4 - 11)	7.9 (5.3 - 11)	9.5 (7.6 - 12)		3.4 (2.7 - 4.3)	4.8 (3.6 - 6.3)	2.0 (1.3 - 3.1)		1.1 (0.7 - 1.7)	1.2 (0.6 - 2.1)	1.1 (0.6 - 1.9)		6.8 (5.7 - 8.0)	4.2 (3.0 - 5.7)	8.9 (7.3 - 11)	
Age-adjusted diabetes prevalence (%)	9.0 (7.8 - 10)	6.3 (4.9 - 7.9)	12 (9.7 - 14)	<0.01	5.3 (4.1 - 6.4)	5.7 (4.0 - 8.1)	5.0 (3.6 - 6.8)	0.56	7.4 (6.0 - 8.9)	7.2 (4.6 - 11)	7.5 (5.8 - 9.6)	0.86	3.3 (2.5 - 4.0)	4.7 (3.5 - 6.3)	1.8 (1.1 - 2.8)	<0.01	1.3 (0.7 - 1.9)	1.3 (0.6 - 2.4)	1.3 (0.6 - 2.5)	>0.99	6.7 (5.6 - 7.8)	4.1 (2.9 - 5.7)	9.1 (7.3 - 11)	<0.01
Aware of having diabetes (n)	120	51	69		55	22	33		61	16	45		18	16	2		15	8	7		59	17	42	
Aware of having diabetes (%)	63 (56 - 70)	71 (59 - 81)	58 (49 - 67)	0.08	60 (49 - 70)	55 (39 - 71)	64 (50 - 76)	0.41	58 (48 - 68)	57 (37 - 76)	58 (47 - 70)	0.90	25 (16 - 37)	32 (20 - 47)	9.5 (1.2 - 30)	0.05	65 (43 - 84)	73 (39 - 94)	58 (28 - 85)	0.47	45 (36 - 54)	46 (30 - 63)	45 (34 - 55)	0.90
Reporting treatment for diabetes (n)	NA	NA	NA		41	18	23		54	11	43		4	3	1		7	4	3		46	14	32	
Reporting treatment for diabetes (%)	NA	NA	NA		75 (61 - 85)	82 (60 - 95)	70 (51 - 84)	0.31	89 (78 - 95)	69 (41 - 89)	96 (85 - 100)	<0.01	22 (6.4 - 48)	19 (4 - 46)	50 (1.3 - 99)	0.32	47 (21 - 73)	50 (16 - 84)	43 (9.9 - 82)	0.78	78 (65 - 88)	82 (57 - 96)	76 (61 - 88)	0.60
Diabetes controlled (n)	NA	NA	NA		13	5	8		25	4	21		2	1	1		4	3	1		14	6	8	
Diabetes controlled (%)	NA	NA	NA		32 (18 - 48)	28 (9.7 - 54)	35 (16 - 57)	0.63	46 (33 - 60)	36 (11 - 69)	49 (33 - 65)	0.46	50 (6.8 - 93)	33 (0.8 - 91)	100 (-)	0.68	57 (18 - 90)	75 (19 - 99)	33 (0.8 - 91)	0.27	30 (18 - 46)	43 (18 - 71)	25 (12 - 43)	0.23

T: total, M:men, W:women; prevalences are given as estimates and 95% confidence intervals. p value for men vs women and calculated using chi-squared or Fisher's exact test. NA-not applicable as these data were not collected

Table S3. Factors associated with odds of having diabetes across three sub-Saharan African sites with high HIV prevalence (Agincourt, Dikgale & Nairobi)[1]

	Odds ratio	95% confidence interval	p value
Age	1.1	1.0-1.1	<0.01
Sex			
Women	reference		
Men	0.8	0.5-1.2	0.21
Marital status			
Currently married or cohabitating	reference		
Never marrried or cohabitating	1.2	0.8-1.8	0.37
Previously married	1.0	0.8-1.4	0.91
Educational attainment			
No formal education	reference		
Primary education	1.5	1.0-2.2	0.07
Secondary education	1.2	0.8-1.9	0.44
Tertiary education	1.2	0.6-2.6	0.60
Employment status			
Unemployed	reference		
Employed	1.2	0.9-1.6	0.19
Smoking status			
No history of smoking	reference		
Current smoker	0.6	0.4-1.1	0.08
History of hypertension			
No	reference		
Yes	2.0	1.5-2.6	<0.01
HIV status			
Negative	reference		
Positive	0.5	0.4-0.8	<0.01
Family history of diabetes			
No	reference		
Yes	3.6	2.8-4.7	<0.01
Physical activity categories			
Absent	reference		
Insufficient	1.4	0.7-3.0	0.33
Sufficient	1.1	0.6-2.0	0.73
Hip circumference	1.0	1.0-1.0	<0.01
Visceral fat	1.2	1.1-1.2	<0.01
Subcutaneous fat	1.3	1.1-1.4	<0.01

[1]3929 participants were included in the analysis

Table S4. Factors associated with odds of having diabetes across two sub-Saharan African sites with low HIV prevalence (Navrongo & Nanoro)[1]

	Odds ratio	95% confidence interval	p value
Age	1.0	1.0-1.1	0.18
Sex			
Women	reference		
Men	1.9	1.1-3.3	0.03
Marital status			
Currently married or cohabitating	reference		
Never married or cohabitating	1.8	0.2-14.2	0.58
Previously married	1.2	0.6-2.3	0.68
Educational attainment			
No formal education	reference		
Primary education	0.5	0.2-1.2	0.12
Secondary education	0.9	0.4-2.5	0.91
Tertiary education	3.7	1.0-13.9	0.05
Employment status			
Unemployed	reference		
Employed	1.8	0.8-3.9	0.13
Smoking status			
No history of smoking	reference		
Current smoker	0.9	0.3-2.6	0.79
History of hypertension			
No	reference		
Yes	1.2	0.7-2.1	0.50
HIV status			
Negative	reference		
Positive	1.7	0.2-13.5	0.63
Family history of diabetes			
No	reference		
Yes	10.4	4.3-25.4	<0.01
Physical activity categories			
Absent	reference		
Insufficient	0.5	0.1-1.7	0.23
Sufficient	0.5	0.3-0.8	0.01
Hip circumference	1.0	1.0-1.1	0.02
Visceral fat	1.2	1.0-1.4	0.14
Subcutaneous fat	1.1	0.7-1.9	0.72

[1]3496 participants were included in the analysis

Table S5. Factors associated with awareness in high HIV prevalence sites (Agincourt, Dikgale, Nairobi & Soweto)[1]

	Odds Ratio	95% confidence interval	p value
Age	1.0	1.0-1.1	0.09
Sex			
Women	reference		
Men	1.0	0.6-1.6	0.85
Marital status			
Currently married or cohabitating	reference		
Never married or cohabitating	1.0	0.5-2.1	0.93
Previously married	0.9	0.5-1.4	0.60
Educational attainment			
No formal education	reference		
Primary education	1.1	0.5-2.3	0.86
Secondary education	1.4	0.7-3.2	0.37
Tertiary education	1.2	0.4-3.9	0.79
Employment status			
Unemployed	reference		
Employed	0.8	0.5-1.2	0.20
History of hypertension			
No	reference		
Yes	1.9	1.2-2.9	0.01
HIV status			
Negative	reference		
Positive	2.1	1.1-4.0	0.03
Body mass index	1.0	0.9-1.0	0.17

[1]397 participants were included in the analysis

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	3
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	3-4
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	6-7
Objectives	3	State specific objectives, including any prespecified hypotheses	7
Methods			
Study design	4	Present key elements of study design early in the paper	7-8
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	7-8
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	7-8
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	8-10
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	8-10
Bias	9	Describe any efforts to address potential sources of bias	10-11
Study size	10	Explain how the study size was arrived at	7-8
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	10-12
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	10-12
		(*b*) Describe any methods used to examine subgroups and interactions	10-12
		(*c*) Explain how missing data were addressed	12
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	n/a
		(*e*) Describe any sensitivity analyses	11-12
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	12,15
		(b) Give reasons for non-participation at each stage	15
		(c) Consider use of a flow diagram	
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	12-14
		(b) Indicate number of participants with missing data for each variable of interest	13-15, 17, 18
Outcome data	15*	Report numbers of outcome events or summary measures	15

Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	16
		(*b*) Report category boundaries when continuous variables were categorized	n/a
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	n/a
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	16
Discussion			
Key results	18	Summarise key results with reference to study objectives	18
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	20-21
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	18-22
Generalisability	21	Discuss the generalisability (external validity) of the study results	21
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	23-24

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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Diabetes care cascade and associated factors in 10,700 middle-aged adults in four sub-Saharan African countries-a cross-sectional study

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Full title: Diabetes care cascade and associated factors in 10,700 middle-aged adults in four sub-Saharan African countries - a cross-sectional study

Running title: Diabetes care cascade in sub-Saharan Africa

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Word counts:

Abstract: 277 words

Main text: 3771 words

Abstract

Objectives: We investigated progression through the care cascade and associated factors for people with diabetes in sub-Saharan Africa to identify attrition stages that may be most appropriate for targeted intervention.

Design: Cross-sectional study.

Setting: Community-based study in four sub-Saharan African countries.

Participants: 10 700 individuals, aged 40-60 years.

Primary and secondary outcome measures: The primary outcome measure was the diabetes cascade of care defined as the age-adjusted diabetes prevalence (self-report of diabetes, fasting plasma glucose [FPG]≥7 mmol/l or random plasma glucose≥11.1 mmol/l) and proportions of those who reported awareness of having diabetes, ever having received treatment for diabetes and those who achieved glycaemic control (FPG<7.2 mmol/l). Secondary outcome measures were factors associated with having diabetes and being aware of the diagnosis.

Results: Diabetes prevalence was 5.5% (95%CI 4.4-6.5%). Approximately half of those with diabetes were aware (54%; 95%CI 50-58%); 73% (95%CI 67-79%) of aware individuals reported ever having received treatment. However, only 38% (95%CI 30-46%) of those ever having received treatment were adequately controlled. Increasing age (OR 1.1; 95%CI 1.0-1.1), urban residence (OR 2.3; 95%CI 1.6-3.5), hypertension (OR 1.9; 95%CI 1.5-2.4), family history of diabetes (OR 3.9;

95%CI 3.0-5.1), and measures of central adiposity were associated with higher odds of having diabetes. Increasing age (OR 1.1; 95%CI 1.0-1.1), semi-rural residence (OR 2.5; 95%CI 1.1-5.7), secondary education (OR 2.4; 95%CI 1.2-4.9), hypertension (OR 1.6; 95%CI 1.0-2.4), and known HIV positivity (OR 2.3; 95%CI 1.2-4.4) were associated with greater likelihood of awareness of having diabetes.

Conclusions: There is attrition at each stage of the diabetes care cascade in sub-Saharan Africa. Public health strategies should target improving diagnosis in high-risk individuals and intensifying therapy in individuals treated for diabetes.

Keywords: diabetes mellitus, sub-Saharan Africa

Strength and limitations of this study

- We present harmonised primary data on the diabetes care cascade from multiple countries in sub-Saharan Africa
- Our study included over 10,000 participants from eastern, western and southern Africa
- We did not perform glucose tolerance testing and therefore may not have identified individuals who met criteria for diabetes diagnosis only after a glucose challenge
- Glycaemic control was assessed using fasting plasma glucose which provides a point evaluation and may not be reflective of control over a longer period of time

INTRODUCTION

Diabetes prevalence in adults in sub-Saharan Africa (SSA) is projected to increase from 23.6 million in 2021 to 54.9 million people in 2045.[1] Inadequate control of blood sugar and other cardiovascular risk factors will impose an unsustainable burden of diabetes-related complications on already constrained regional health care systems. Existing data suggest that outcomes in individuals in SSA with diabetes are currently suboptimal with over 300,000 diabetes-related deaths before the age of 60 years in 2021,[1] highlighting the need to improve clinical care. Optimisation of diabetes management is contingent on numerous factors including the diagnosis of diabetes, appropriate escalation of therapy and patient adherence to therapeutic interventions, but effective strategies to improve diabetes management in SSA are hampered by a lack of knowledge about the extent of the deficiencies in this care continuum.

The cascade of care model, frequently used to identify deficits in HIV care, may be applied to diabetes to identify opportunities for improved outcomes.[2-4] The elements of the cascade, namely prevalence, awareness, treatment and control reflect aspects of the health care system, including effectiveness of prevention and detection strategies and the ability to implement and escalate therapy as necessary. On an individual level, diabetes awareness in particular is key to the adherence to lifestyle modification and medication that underpin glycaemic control. Evaluation of the diabetes care cascade allows policy makers to assess how well the health care system manages patients with diabetes and to identify areas for targeted interventions, particularly important in the resource-constrained lower and middle-income countries of SSA.

Despite the benefits of establishing the diabetes care cascade, there is a paucity of primary data on it in SSA. Studies have often been limited to diabetes prevalence and awareness and conducted in hospital-based populations, introducing selection bias, while multi-country studies that have reported on the entire cascade have meta-analysed data from heterogeneous studies with methodological differences in determining each cascade stage.[2,3] We aimed to evaluate the diabetes cascade of care in four SSA countries, using harmonised data collected across six sites, and performed exploratory analyses of the cascade stratified by sex and study site. We further investigated factors associated with the likelihood of having diabetes and being aware of a diagnosis of diabetes, the first two steps in the cascade.

METHODS

Study Setting and Participants

The AWI-Gen study and participating sites have been described in detail elsewhere.[5,6] In brief, 10,700 individuals were recruited from six sites in SSA in a community-based, cross-sectional study conducted between August 2013 and August 2016. Individuals were eligible for inclusion if they were aged 40-60 years and resided permanently in the study sites. We excluded individuals who were pregnant and, given that one of the broader objectives of the AWI-Gen study was to investigate genomic determinants of cardiometabolic disease, we also excluded individuals who were closely related to an existing participant and who had recently immigrated into the study site. We selected individuals aged 40-60 years as this is a peak time for the development of cardiometabolic disease. Three of the study sites were in South Africa (Soweto, Agincourt and Dikgale), one was in Kenya (Nairobi),

one in Ghana (Navrongo) and one in Burkina Faso (Nanoro). Participants were therefore included from southern, eastern and western Africa. The selected sites were also on a continuum of urbanisation: Nairobi and Soweto were urban sites, Agincourt and Dikgale were semi-rural and Nanoro and Navrongo were rural.

With the exception of Soweto, each study site is home to a Health and socio-Demographic Surveillance System (HDSS) which enumerates all residents within the HDSS on a regular basis, ensuring a well-defined population sampling frame. In Nairobi, Agincourt, Navrongo and Nanoro, individuals were randomly sampled from the sampling frame, while in Dikgale, a convenience sampling strategy was employed. In Soweto, 700 women who were participants in the Study of Women Entering an Endocrine Transition (SWEET) study[7] and caregivers of the Birth to Twenty+ cohort[8] were recruited. Additional female and all male participants were randomly recruited, using a sampling frame which covered the Soweto region. Where necessary, there was oversampling to ensure equal numbers of women and men.

Patient and public involvement

Prior to the initiation of the AWI-Gen study, an extensive process of community engagement was conducted. This included meetings with civic and traditional leadership structures, household visits and group information sessions to discuss planned research activities. Study results were delivered annually to study participants, communities and community leaders.

Data Collection and Definitions

Data were collected by study staff trained on standardised protocols. Sociodemographic data and personal and family medical history were self-reported. Additionally, individuals were considered to have hypertension if the mean systolic blood pressure of the latter two of three readings at the study visit ≥140 mmHg or the mean diastolic pressure ≥90 mmHg (Omron M6, Omron, Kyoto, Japan).[9] Individuals were classified as HIV positive if they reported a previous diagnosis of HIV or if they tested positive on the rapid HIV tests that were offered to participants in South Africa and Kenya (MD HIV 1/2 test [Medical Diagnostech, Cape Town, South Africa]; One Step anti-HIV1+2 rapid screen test [InTec, Xiamen, China]; Determine rapid test kit [Abbot Pharmaceuticals, Chicago, USA]). Rapid HIV tests were not offered in Ghana and Burkina Faso due to the low prevalence of HIV in those countries; individuals in these sites who did not know their HIV status were classified as HIV negative. Physical activity was assessed using the Global Physical Activity Questionnaire and occupational, leisure time and travel-related physical activity variables from this questionnaire were summed to give the total moderate-vigorous intensity physical activity (MVPA) in minutes per week. Individuals were classified as having no MVPA (0 minutes/week), insufficient MVPA (1-150 minutes/week) or sufficient MVPA (≥150 minutes/week).[10]

Standing height was measured with the participant barefoot or in light socks, using a Harpenden digital stadiometer (Holtain, Wales, UK). Weight was measured with the participant in light clothing, using a digital Physician Large Dial 200 kg capacity scale (Kendon Medical, South Africa) and body mass index was calculated as weight in kg divided by height in metres squared. Using a stretch-resistant measuring tape

(SECA, Hamburg, Germany), hip circumference, as a measure of gluteofemoral fat, was measured around the most protruding part of the buttocks.

Visceral and subcutaneous adipose tissue, direct measures of central adiposity associated with insulin resistance, were measured using abdominal ultrasound (LOGIQ e ultrasound system [GE Healthcare, CT, USA]). Study staff from all sites were centrally trained in Johannesburg, South Africa to perform the abdominal ultrasounds. Visceral adipose thickness was determined by the thickness of the fat pad between the anterior spine and peritoneal layer at end expiration, while subcutaneous adipose thickness was the thickness of the fat pad between the skin and the outer edge of the linea alba.

Venous blood was collected at study visits in potassium oxalate/sodium fluoride tubes and centrifuged immediately after collection, with the supernatant plasma stored at -80°C until analysis, according to a detailed sample processing protocol provided to all sites. Analyses for glucose were all performed at a central site, using colorimetric methods, on the Randox Plus clinical chemistry analyser (Randox, UK) with a range of 0.36–35 mmol/l and coefficient of variation<2.3%.

Diabetes was defined as a previous diagnosis of diabetes by a health care provider (which could include a doctor, nurse, community health worker or similar person), ever having received treatment for diabetes, or fasting plasma glucose ≥7 mmol/l or random plasma glucose ≥11.1 mmol/l [11,12] on the sample taken during the study visit. Samples were considered random if a participant had not fasted overnight or fasting status could not be confirmed. Participants were considered to be aware of a

diagnosis of diabetes if they reported ever having been told by a health care provider that they had diabetes and were considered to have been treated for diabetes if they reported ever having received treatment for diabetes (dietary advice and/or glucose lowering agents) from a health care provider. Individuals were considered to have their diabetes controlled if fasting glucose was <7.2 mmol/l.[11]

Statistical Analysis

Categorical participant characteristics of marital status, highest level of education, current smoking, known hypertension, known HIV positivity, family history of diabetes and physical activity category were described using frequencies and percentages, while medians and interquartile ranges (IQR) were used to describe continuous characteristics of age, body mass index, hip circumference, visceral fat and subcutaneous fat. The Mann-Whitney U, chi-squared and Fisher's exact tests were used to compare continuous and categorical variables respectively between groups defined by sex to investigate sex-related differences in potential determinants and groups defined by data missingness status to evaluate for bias between those who were included and those who were excluded from the analysis due to missing data.

Age-adjusted diabetes prevalence was determined using the United Nations African population distribution[13] as the reference population structure. The proportion of those aware of having diabetes was calculated as a percentage of those with diabetes and similarly, the proportion of those ever receiving treatment for diabetes was calculated as a percentage of those aware of having diabetes. The proportion of those who had their diabetes controlled was calculated as a percentage of those

who reported ever receiving treatment. The method for interval estimation described by Tiwari et al.[14] was used to determine the 95% confidence intervals. The Soweto site was excluded from the latter two stages of the cascade as the 'ever receiving treatment' variable was not collected.

Multivariable logistic regression was used to assess the relationship between the odds of having diabetes and sociodemographic and clinical characteristics including urbanicity. Independent variables for inclusion in the logistic regression were selected based on previous research.[15,16] The Soweto site did not collect data on family history of diabetes and was therefore not included in this model, as family history of diabetes has been demonstrated in other settings to be strongly associated with higher odds of having the condition. Additional multivariable logistic regression models were also fit, using data from all sites, to investigate associations with awareness of a diagnosis of diabetes. In the model investigating associations with odds of having diabetes, we included visceral and subcutaneous fat as direct assessments of central obesity and hip circumference as a measure of gluteofemoral fat. In the model investigating associations with awareness, we used body mass index as the measure of obesity as we thought awareness was more likely to be associated with a global assessment of obesity rather than individual fat depots. We were underpowered to assess associations with diabetes treatment and control.

Sensitivity analyses were conducted in which associations with having diabetes and awareness of a diagnosis of diabetes were explored in analyses stratified by HIV prevalence, with the South African sites and Nairobi classified as high prevalence sites and Navrongo and Nanoro classified as low prevalence sites.

Missing data were handled using pairwise deletion. Analyses were conducted using Stata v16 (StataCorp, USA).

RESULTS

Sample Characteristics

The characteristics of the 10,700 study participants are shown in Supplemental Table S1. There were 5,892 women (55%), with a median age of 50 years (IQR 45-55). There was some inter-site variation in sociodemographic variables - while most participants in the urban and semi-rural sites had some formal education, between 70-80% of participants in the rural sites did not. Smoking prevalence ranged between 6% and 30% overall, with prevalence several fold higher in men than in women in all sites. There was a high prevalence of chronic disease with 3,755 (37%) participants having hypertension and 1,310 (12%) known as being HIV positive, although inter-site variation was evident, with HIV prevalence being low, for example, in Nanoro and Navrongo. Family history of diabetes was highest in the urban and semi-rural areas. Anthropometric measures of obesity and subcutaneous fat were higher in women in urban and semi-urban areas, while there were no clear sex differences in Nanoro or Navrongo. Visceral fat was generally similar in both sexes. The majority of individuals (82%) were undertaking at least 150 minutes of moderate to vigorous physical activity weekly.

Missing Outcome Data

No participants had missing data on the diabetes status outcome, while 31 individuals had missing data on the awareness outcome and were slightly older (median age 54 vs 52 years; p=0.04), less likely to be employed (32 vs 64%; p<0.01) and had a different marital status distribution (p<0.01) than those who were not missing these data.

Diabetes Cascade of Care

The diabetes cascade of care is shown in Figure 1. The age-adjusted prevalence of diabetes in study participants was 5.5% (95%CI 4.4-6.5%) and was significantly higher in women (6.1% vs 4.9%; p<0.01). Prevalence varied by site, with highest prevalence in the urban site of Soweto (9.0%; 95%CI 7.8-10%) and the lowest in rural Navrongo (1.3%; 95%CI 0.7-1.9%) (Supplemental Table S2). Diabetes prevalence was higher in women than men in Soweto and Nairobi (Soweto: 12% vs 6.3%, p<0.01; Nairobi: 9.1% vs 4.1%, p<0.01) while in Nanoro, the prevalence was higher in men (1.8% vs 4.7%, p<0.01).

Overall, just over half of the 613 individuals with diabetes were aware of their condition (54%; 95%CI 50-58%), with the highest awareness in Navrongo (65%; 95%CI 43-84%) and the lowest in Nanoro (25%; 95%CI 16-37%), although confidence intervals across the sites were wide and overlapping. Nearly 75% of individuals aware of having diabetes reported ever receiving treatment, but only 38% (95%CI 30-41%) were adequately controlled. More women reported ever being treated for diabetes (p=0.01), but there were no sex differences in participants achieving control (p=0.98).

In logistic regression models, increasing age (odds ratio [OR] 1.1; 95%CI 1.0-1.1; p<0.01) and urban residence (OR 2.3; 95%CI 1.6-3.5; p<0.01) were associated with higher odds of having diabetes (Table 1). Hypertension was also associated with having diabetes (OR 1.9; 95%CI 1.5-2.4; p<0.01), as was family history of diabetes (OR 3.9; 95%CI 3.0-5.1; p<0.01); conversely, known HIV positivity was associated with lower odds of diabetes (OR 0.6; 95%CI 0.4-0.9; p<0.01). Visceral and subcutaneous fat were also associated with higher odds, while there was a marginal negative association with hip circumference (Table 1).

Similar associations were evident in sensitivity analyses restricted to sites with high HIV prevalence (Supplemental Table S3). However, only family history remained significantly associated with diabetes in low HIV prevalence settings, although previously unobserved associations with male sex and physical activity emerged (Supplemental Table S4). These analyses were however limited by the low prevalence of diabetes in these settings which meant they were underpowered.

Increasing age (OR 1.1; 95%CI 1.0-1.1; p=0.02), semi-rural environment (OR 2.5; 95%CI 1.1-5.7; p=0.02) and secondary education (OR 2.4; 95%CI 1.2-4.9; p=0.02) were all associated with greater likelihood of awareness of diabetes, as were the chronic conditions of hypertension (OR 1.6; 95%CI 1.0-2.4; p=0.04) and known HIV positivity (OR 2.3; 95%CI 1.2-4.4; p=0.02) (Table 2). In sensitivity analyses in high HIV prevalence sites, only hypertension and known HIV positivity remained associated with higher awareness of diabetes (Supplemental Table S5). The sample size in low HIV prevalence sites was too small to perform meaningful analyses.

Table 1. Factors associated with odds of having diabetes in five sub-Saharan African sites (Agincourt, Dikgale, Nairobi, Nanoro & Navrongo)[1]

	Odds Ratio	95% confidence interval	p value
Age	1.1	1.0-1.1	<0.01
Sex			
Women	reference		
Men	1.1	0.8-1.5	0.65
Location			
Rural	reference		
Semi-rural	1.5	1.0-2.3	0.08
Urban	2.3	1.6-3.5	<0.01
Marital status			
Currently married or cohabitating	reference		
Never married or cohabitating	1.4	0.9-2.0	0.15
Previously married	1.0	0.8-1.3	0.99
Educational attainment			
No formal education	reference		
Primary education	1.2	0.9-1.7	0.29
Secondary education	1.0	0.7-1.5	0.84
Tertiary education	1.4	0.7-2.6	0.37
Employment status			
Unemployed	reference		
Employed	1.1	0.8-1.5	0.48
Smoking status			
No history of smoking	reference		
Current smoker	0.7	0.4-1.1	0.15
History of hypertension			
No	reference		
Yes	1.9	1.5-2.4	<0.01
Known HIV positivity			
No	reference		
Yes	0.6	0.4-0.9	0.01
Family history of diabetes			
No	reference		
Yes	3.9	3.0-5.1	<0.01
Physical activity categories			
Absent	reference		
Insufficient	0.9	0.5-1.5	0.61
Sufficient	0.7	0.5-1.0	0.08
Hip circumference	1.0	1.0-1.0	0.04
Visceral fat	1.2	1.1-1.2	<0.01
Subcutaneous fat	1.3	1.1-1.4	<0.01

[1]7,425 participants were included in the analysis. Participants from the Soweto site were excluded as data on family history were not collected. Age was entered as a continuous variable

Table 2. Factors associated with awareness of diabetes in six sub-Saharan African sites (Agincourt, Dikgale, Nairobi, Nanoro, Navrongo & Soweto)[1]

	Odds Ratio	95% confidence interval	p value
Age	1.0	1.0-1.1	0.02
Sex			
Women	reference		
Men	1.1	0.7-1.8	0.59
Location			
Rural	reference		
Semi-rural	2.5	1.1-5.7	0.02
Urban	1.5	0.7-3.1	0.34
Marital status			
Currently married or cohabitating	reference		
Never married or cohabitating	0.9	0.4-2.0	0.84
Previously married	1.0	0.6-1.7	0.86
Educational attainment			
No formal education	reference		
Primary education	1.8	0.9-3.5	0.09
Secondary education	2.4	1.2-4.9	0.02
Tertiary education	2.1	0.7-6.1	0.17
Employment status			
Unemployed	reference		
Employed	0.8	0.5-1.3	0.45
History of hypertension			
No			
Yes	1.6	1.0-2.4	0.04
Known HIV positivity			
No	reference		
Yes	2.3	1.2-4.4	0.02
Body mass index	1.0	1.0-1.0	0.97

[1]472 participants were included in the analysis. Age and body mass index were entered as continuous variables.

DISCUSSION

In this multi-country study of the diabetes care cascade in SSA, we demonstrate attrition at each stage of the cascade with just over half of those with diabetes being aware of their condition and only approximately a third of those who reported ever receiving treatment achieving optimal glycaemic control. We also report sociodemographic and clinical factors associated with increased odds of having diabetes including older age, urban residence and having hypertension and factors associated with awareness of having diabetes which included increasing age, semi-

rural environment, secondary education and having hypertension or known HIV positivity.

Our prevalence estimate of 5.5% is similar to the 2019 International Diabetes Federation (IDF) estimate for SSA of 4.7% in adults aged 20-79 years.[1] A sub-regional meta-analysis from western Africa revealed a lower prevalence (4.0% in urban adults and 2.6% in rural adults),[17] in keeping with our study where prevalence in the western African sites was two to three times lower than in the southern and eastern African sites. Factors in our study associated with higher odds of having diabetes, such as increasing age and urban residence, have been previously reported, with the western African meta-analysis reporting over a threefold increase in prevalence in people over 50 years[17] and Werfalli et al. reporting a prevalence of 20% in people living in urban areas vs 7.9% in those in rural areas.[18] Our findings of associations with family history of diabetes, hypertension and adiposity support results from other country-level meta-analyses in Africa.[19,20] We also noted lower odds of having diabetes in individuals with known HIV in keeping with other studies that have identified lower prevalence of cardiometabolic risk factors in individuals with HIV in SSA.[21,22]

While our estimate of the prevalence of diabetes unawareness of 47% was broadly similar to the 2019 IDF estimate of the prevalence of undiagnosed diabetes of 60% in SSA,[1] it did contrast sharply with other studies. A meta-analysis of 23 studies from across Africa estimated a much lower pooled prevalence of undiagnosed diabetes of just under 4%.[23] There was however significant heterogeneity in the included studies and the majority of the data originated from a single country, which

may not be representative of other countries in the region. This itself differed considerably from data from 12 nationally representative surveys in SSA in which 73% of those with diabetes were unaware of their condition, with factors similar to our study, namely older age and higher level of educational attainment, associated with awareness.[24] Our findings also suggest that those with chronic diseases such as HIV and hypertension may be more aware of having diabetes, which may be due to increased contact with the health care system.[25]

In a study reporting data from 15 sub-Saharan African countries, approximately 40% of adults with diabetes received glucose-lowering medication, while approximately 25% received counselling on diet, exercise or weight loss.[2] These proportions are lower than ours which may be due to the difference in denominators - we used a denominator of individuals aware of having diabetes rather than all those with diabetes. In another study reporting data from 12 sub-Saharan African countries, just over 30% of those with diabetes were aware of their condition, with a similar percentage ever having received lifestyle advice or currently receiving diabetes medication and just over 20% achieving control. [3] While this study also used a fixed denominator of the number of people with diabetes, the results support our finding that there is not a major fall-off between the stages of awareness and treatment and the most significant deficits are at the stages of awareness of having diabetes i.e., diagnosis and achieving glycaemic control. Of note, this study used a more liberal definition of glycaemic control than our study (FPG <10.1 mmol/l or glycosylated haemoglobin (HbA_{1c}) <8% in the single study in which it was available) and may have identified a more drastic control deficit if a threshold for glycaemic control similar to ours had been used. A country-level meta-analysis of 22 studies

from Ethiopia suggested a similar degree of glycaemic control as our study, with approximately a third of those included achieving glycaemic targets, regardless of whether these were assessed using fasting plasma glucose or HbA_{1c}.[26]

We describe, to our knowledge, the first study in SSA in which harmonised primary data on the diabetes care cascade have been collected from multiple countries. Previous multi-country research in SSA on this subject has relied on systematic reviews and meta-analyses and has therefore been limited by the methodological heterogeneity of the constituent studies, including the use of different biomarkers to define diabetes. In our work, data were collected in a standardised manner and in addition to self-report, we used venous blood samples, analysed at a single laboratory, to ascertain biochemical evidence of diabetes. Our study also included over 10,000 men and women from three sub-regions of SSA.

Our study does have limitations. We did not distinguish between type 1 and type 2 diabetes and the care cascade and associated factors may differ between these two conditions. While we used accepted and convenient diagnostic criteria for diabetes, we may have underestimated the prevalence of diabetes as we did not assess glucose tolerance and may therefore have excluded those who met the criteria for diabetes only after a glucose challenge, which may be particularly important in populations of African descent. Both oral glucose tolerance tests and HbA_{1c}, appear to classify more African-ancestry individuals as having diabetes than FPG alone [27, 28] and use of either of these criteria may have increased diabetes prevalence in our study. Our research was conducted in HDSS sites and among a research cohort in Soweto, populations which may not be nationally representative. Indeed, individuals

in these sites may have been told they had diabetes while taking part in previous studies, making the proportion of individuals with diabetes who know they have the condition higher than in the general population. We also used self-report rather than clinical records to determine ever receiving diabetes treatment. Fasting plasma glucose was used to assess diabetes control and this provides an evaluation only at a single point in time and may be subject to more analytic variability than HbA_{1c}, which has largely supplanted it in clinical use in well-resourced environments. Several large scale epidemiological studies have however used plasma glucose measures to assess glycaemic control.[2,3] We collected data for this study between 2013 and 2016 and it is conceivable that some of the parameters in the cascade may have changed during or since that time.

Despite these limitations, our study provides valuable information on the burden of diabetes in SSA and the deficiencies which need to be addressed to improve outcomes. In areas where diabetes prevalence is low, primordial prevention strategies should be employed to reduce the likelihood of developing risk factors such as obesity, with particular focus on higher risk urban environments. Screening of at-risk populations needs to be enhanced and the low percentage of individuals attaining satisfactory glycaemic control suggests that more aggressive, treat to target strategies need to be promoted among health care workers, although we acknowledge this may be limited by drug availability in many parts of the continent.

Additional work is necessary to understand whether our findings are applicable to other SSA countries and sub-regions at different stages of the epidemiological transition and with variable access to health care. It is also essential to understand

key determinants of ever receiving diabetes treatment and control, which we were underpowered to investigate, and care cascades for other important vascular risk factors in people with diabetes, such as elevated blood pressure and dyslipidaemia. Identification of the points in each of these care cascades at which significant attrition is occurring will assist public health officials in developing appropriate interventions to reduce diabetes-related morbidity and mortality.

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ANW and MR had full access to all the data in the study and take responsibility for the integrity of the data. IM performed the data analysis and takes responsibility for its accuracy. All authors consent to the publication of this manuscript and agree to be accountable for all aspects of this work.

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Data statement: De-identified individual participant data from the AWI-Gen study are available from the European Genome-Phenome Archive (EGA) at study number EGA00001002482 [https://ega459 archive.org/datasets/EGAD00001006425].

Ethics Approval

Written informed consent was provided by participants in their local languages. Ethical approval for the AWI-Gen study was provided by the Human Research Ethics Committee (Medical) of the University of the Witwatersrand (M121029, M170880). Each of the HDSS centres also obtained ethical approval according to their respective institutional and country-specific regulations.

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Figure 1. Diabetes cascade of care in six sub-Saharan African countries, overall and stratified by gender

Estimates given as counts and proportions with 95% confidence intervals and proportions calculated as percentages of eligible individuals in previous stage. Estimates for ever receiving treatment and achieving glycaemic control (calculated as percentage of those who ever received treatment) exclude Soweto as the treatment variable was not collected at that site. Data on diabetes control were missing for a further 17 participants.

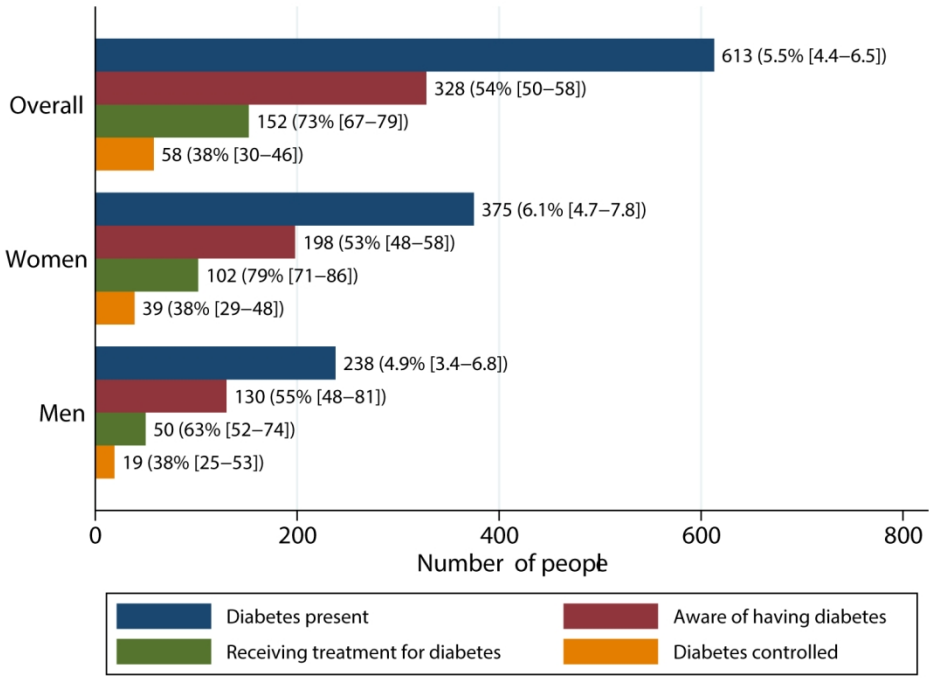

Figure 1. Diabetes cascade of care in six sub-Saharan African countries, overall and stratified by gender
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Supplemental material

Supplemental Table S1. Demographic and clinical characteristics of 10,700 study participants in six sub-Saharan African sites

Supplemental Table S2. Diabetes care cascade by study site

Supplemental Table S3. Factors associated with odds of having diabetes across three sub-Saharan African sites with high HIV prevalence (Agincourt, Dikgale & Nairobi)

Supplemental Table S4. Factors associated with odds of having diabetes across two sub-Saharan African sites with low HIV prevalence (Navrongo & Nanoro)

Supplemental Table S5. Factors associated with awareness in high HIV prevalence sites (Agincourt, Dikgale, Nairobi & Soweto)

Table S1. Demographic and clinical characteristics of 10,700 study participants in six sub-Saharan African sites

	Soweto			Agincourt			Dikgale			Nanoro			Navrongo			Nairobi			Overall		
	Men	Women	Overall	Men	Women	Overall	Men	Women	Overall	Men	Women	Overall	Men	Women	Overall	Men	Women	Overall	Men	Women	Overall
	n=1,025 51%	n=1,002 49%	n=2,027	n=573 39%	n=892 61%	n=1,465	n=356 31%	n=812 69%	n=1,168	n=1,045 50%	n=1,039 50%	n=2,084	n=923 46%	n=1,091 54%	n=2,014	n=886 46%	n=1,056 54%	n=1,942	n=4,808 45%	n=5,892 55%	n=10,700
Age (years)	49 (44-55)	49 (44-54)	49 (44-54)	51 (45-56)	51 (46-56)	51 (46-56)	50 (45-55)	51 (46-56)	51 (45-55)	50 (44-55)	50 (45-54)	50 (45-55)	50 (46-55)	52 (47-56)	51 (46-56)	48 (44-53)	48 (44-52)	48 (44-53)	50 (45-55)	50 (45-55)	50 (45-55)
Marital status (%)																					
Currently married/ Cohabitating	570 (56)	266 (27)	836 (41)	445 (78)	537 (60)	982 (67)	178 (50)	427 (53)	605 (52)	1,021 (98)	794 (76)	1,815 (87)	787 (85)	694 (64)	1,481 (74)	808 (91)	486 (46)	1,294 (67)	3,809 (79)	3,204 (54)	7,013 (66)
Never married/ cohabitating	265 (26)	51 (5.1)	316 (16)	75 (13)	59 (6.6)	134 (9.2)	103 (29)	185 (23)	288 (25)	14 (1.3)	3 (0.3)	17 (0.8)	15 (1.6)	5 (0.5)	20 (1.0)	13 (1.5)	70 (6.6)	83 (4.3)	485 (10)	373 (6.3)	858 (8.0)
Previously married	189 (19)	347 (35)	536 (26)	53 (9.2)	296 (33)	349 (24)	75 (22)	200 (25)	275 (24)	8 (0.8)	238 (23)	246 (12)	120 (13)	392 (36)	512 (26)	65 (7.3)	499 (47)	564 (29)	510 (11)	1,972 (33)	2,482 (23)
Missing	1 (0.1)	338 (34)	339 (17)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	2 (0.2)	4 (0.4)	6 (0.3)	1 (0.1)	0 (0)	1 (0.1)	0 (0)	1 (0.1)	1 (0.1)	4 (0.1)	343 (5.8)	347 (3.2)
Highest level of education (%)																					
No formal education	8 (0.8)	2 (0.2)	10 (0.5)	23 (22)	280 (31)	403 (28)	22 (6.2)	74 (9.1)	96 (8.2)	758 (73)	960 (92)	1,718 (82)	570 (62)	843 (77)	1,413 (70)	34 (3.8)	113 (11)	147 (7.6)	1,515 (32)	2,272 (39)	3,787 (35)
Primary education	117 (11)	636 (64)	753 (37)	235 (41)	340 (38)	575 (39)	113 (32)	273 (34)	386 (33)	181 (17)	58 (5.6)	239 (12)	206 (22)	177 (16)	383 (19)	447 (51)	663 (63)	1,110 (57)	1,299 (27)	2,147 (36)	3,446 (32)
Secondary education	748 (73)	147 (15)	895 (44)	175 (31)	223 (25)	398 (27)	204 (57)	440 (54)	644 (55)	86 (8.2)	10 (1)	96 (4.6)	118 (13)	57 (5.2)	175 (8.7)	383 (43)	276 (26)	659 (34)	1,714 (36)	1,153 (20)	2,867 (27)
Tertiary education	152 (15)	1 (0.1)	153 (7.5)	39 (6.8)	49 (5.5)	88 (6.0)	17 (4.8)	24 (3.0)	41 (3.5)	16 (1.5)	2 (0.2)	18 (0.9)	27 (2.9)	9 (0.8)	36 (1.8)	22 (2.5)	4 (0.4)	26 (1.3)	273 (5.7)	89 (1.5)	362 (3.4)
Missing	0 (0)	216 (22)	216 (10.7)	1 (0.2)	0 (0.0)	1 (0.1)	0 (0)	1 (0.1)	1 (0.1)	4 (0.4)	9 (0.9)	13 (0.6)	2 (0.2)	5 (0.5)	7 (0.4)	0 (0)	0 (0)	0 (0)	7 (0.2)	231 (3.9)	238 (2.2)
Employed (%)	670 (65)	547 (55)	1,217 (60)	197 (34)	303 (34)	500 (34)	160 (45)	279 (34)	439 (37)	1,026 (98)	1,030 (99)	2,056 (99)	599 (65)	659 (60)	1,258 (63)	860 (97)	966 (92)	1,826 (94)	3,512 (73)	3,784 (64)	7,296 (68)
Current smoker (%)	540 (53)	49 (4.9)	589 (29)	155 (27)	3 (0.3)	158 (11)	225 (63)	25 (3.1)	250 (21)	142 (14)	0 (0)	142 (6.8)	388 (42)	21 (1.9)	409 (20)	208 (24)	27 (2.6)	235 (12)	1,658 (35)	125 (2.1)	1,783 (17)
Hypertension (%)	550 (54)	552 (55)	1102 (54)	251 (44)	517 (58)	768 (52)	116 (33)	392 (49)	508 (44)	215 (21)	127 (12)	342 (17)	227 (25)	274 (25)	501 (25)	204 (23)	319 (30)	523 (27)	1,563 (33)	2,181 (37)	3,744 (35)
Known HIV positive (%)	189 (18)	121 (12)	310 (15)	186 (33)	304 (34)	490 (33)	73 (21)	175 (22)	248 (21)	5 (0.5)	4 (0.4)	9 (0.4)	9 (1.0)	6 (0.6)	15 (0.7)	67 (7.6)	171 (16)	238 (12)	529 (11)	781 (13)	1,310 (12)

Family history of diabetes (%)	NA	NA	NA	85 (15)	161 (18)	246 (17)	53 (15)	134 (17)	187 (16)	24 (2.3)	12 (1.2)	36 (1.7)	12 (1.3)	10 (0.9)	22 (1.1)	112 (13)	213 (20)	325 (17)	286 (6.0)	530 (9.0)	816 (7.6)
Body mass index (kg/m^2)	24.2 (20.6-28.5)	32.9 (28.5-37.6)	28.4 (23-33.9)	23 (20.3-26.6)	28.6 (24.1-33.2)	26 (22.1-31.3)	20.6 (18.9-24.1)	30.1 (25.3-35.9)	26.9 (21.1-33.1)	21.1 (19.2-23.4)	19.8 (18.1-21.6)	20.4 (18.6-22.6)	20.6 (19-22.3)	21.4 (19.6-23.9)	21 (19.3-23.1)	22.2 (20-25)	26.9 (23-31.7)	24.4 (21.1-28.6)	21.7 (19.5-24.9)	25.5 (20.8-31.9)	23.2 (20.1-28.6)
Hip circumference (cm)	97.4 (90.0-105.3)	117.5 (109.0-127.0)	107.0 (95.7-118.5)	94.0 (89.0-102.0)	105.0 (97.0-113.0)	100.0 (93.0-110.0)	87.6 (83.3-94.9)	108.7 (98.5-118.9)	101.9 (90.1-114.3)	89.5 (85.6-94.9)	87.8 (83.4-92.5)	88.8 (84.5-93.7)	83.0 (79.0-88.0)	88.0 (83.0-94.0)	86.0 (81.0-91.0)	93.0 (87.4-98.9)	101.0 (94.0-110.0)	97.0 (90.0-104.6)	90.6 (85.0-98.0)	99.0 (89.0-112.0)	94.2 (86.6-105.3)
Subcutaneous fat (cm)	1.4 (0.9-2.0)	.1 (2.5-3.9)	2.2 (1.3-3.2)	1.2 (0.7-1.7)	2.2 (1.5-3.0)	1.7 (1.1-2.7)	0.8 (0.5-1.2)	2.2 (1.6-2.9)	1.7 (0.9-2.6)	0.8 (0.6-1.2)	0.9 (0.6-1.2)	0.9 (0.6 1.2)	0.7 (0.5-0.9)	1.0 (0.7-1.5)	0.8 (0.6-1.2)	1.0 (0.7-1.5)	2.0 (1.4-2.4)	1.5 (1.0-2.1)	0.9 (0.6-1.4)	1.7 (1.0-2.6)	1.2 (0.8-2.1)
Visceral fat (cm)	6.2 (5-7.8)	4.7 (3.5-5.9)	5.5 (4.2-6.9)	6.3 (5.2-7.8)	5.9 (4.2-7.3)	6.1 (4.6-7.5)	5.9 (4.7-7.4)	6.7 (4.9-8.5)	6.4 (4.9-8.2)	4.3 (3.5-5.2)	4.3 (3.6-5.1)	4.3 (3.5-5.1)	4 (3.3-4.8)	3.3 (2.8-4.1)	3.6 (3-4.5)	5 (3.9-6.3)	4.6 (3.6-5.8)	4.8 (3.7-6)	5 (3.9-6.5)	4.5 (3.4-6)	4.7 (3.6-6.2)
Physical activity categories (%)																					
Absent	63 (6.2)	167 (17)	230 (11)	106 (19)	143 (16)	249 (17)	3 (0.9)	8 (1)	11 (1.3)	227 (22)	110 (11)	337 (16)	64 (7.1)	154 (14)	218 (11)	6 (0.7)	19 (1.8)	25 (1.3)	469 (9.8)	601 (10)	1,070 (10)
Insufficient	134 (13)	283 (28)	417 (21)	21 (3.7)	58 (6.5)	79 (5.4)	16 (4.5)	27 (3.3)	134 (6.9)	37 (3.5)	34 (3.3)	71 (3.4)	35 (3.9)	59 (5.4)	94 (4.7)	41 (4.6)	93 (8.8)	134 (6.9)	284 (5.9)	554 (9.4)	838 (7.9)
Sufficient	828 (81)	552 (55)	1,380 (68)	443 (78)	686 (77)	1,129 (78)	334 (95)	776 (96)	1,780 (92)	781 (75)	895 (86)	1,676 (80)	807 (89)	874 (80)	1,681 (84)	839 (95)	941 (89)	1,780 (92)	4,032 (84)	4,724 (80)	8,756 (82)

Continuous variables are summarised as medians and interquartile ranges and categorical variables as n (%); NA-not applicable

Table S2. Diabetes care cascade by study site

	Soweto				Agincourt				Dikgale				Nanoro				Navrongo				Nairobi			
	T	M	W	p	T	M	W	p	T	M	W	p	T	M	W	p	T	M	W	p	T	M	W	p
Sample size	2,027	1,025	1,002		1,465	573	892		1,168	356	812		2,084	1,045	1,039		2,014	923	1,091		1,942	886	1,056	
Diabetes present (n)	191	72	119		92	40	52		105	28	77		71	50	21		23	11	12		131	37	94	
Crude diabetes prevalence (%)	9.4 (8.2 - 11)	7.0 (5.5 - 8.8)	12 (9.9 - 14)		6.3 (5.1 - 7.6)	7.0 (5.0 - 9.4)	5.8 (4.4 - 7.6)		9.0 (7.4 - 11)	7.9 (5.3 - 11)	9.5 (7.6 - 12)		3.4 (2.7 - 4.3)	4.8 (3.6 - 6.3)	2.0 (1.3 - 3.1)		1.1 (0.7 - 1.7)	1.2 (0.6 - 2.1)	1.1 (0.6 - 1.9)		6.8 (5.7 - 8.0)	4.2 (3.0 - 5.7)	8.9 (7.3 - 11)	
Age-adjusted diabetes prevalence (%)	9.0 (7.8 - 10)	6.3 (4.9 - 7.9)	12 (9.7 - 14)	<0.01	5.3 (4.1 - 6.4)	5.7 (4.0 - 8.1)	5.0 (3.6 - 6.8)	0.56	7.4 (6.0 - 8.9)	7.2 (4.6 - 11)	7.5 (5.8 - 9.6)	0.86	3.3 (2.5 - 4.0)	4.7 (3.5 - 6.3)	1.8 (1.1 - 2.8)	<0.01	1.3 (0.7 - 1.9)	1.3 (0.6 - 2.4)	1.3 (0.6 - 2.5)	>0.99	6.7 (5.6 - 7.8)	4.1 (2.9 - 5.7)	9.1 (7.3 - 11)	<0.01
Aware of having diabetes (n)	120	51	69		55	22	33		61	16	45		18	16	2		15	8	7		59	17	42	
Aware of having diabetes (%)	63 (56 - 70)	71 (59 - 81)	58 (49 - 67)	0.08	60 (49 - 70)	55 (39 - 71)	64 (50 - 76)	0.41	58 (48 - 68)	57 (37 - 76)	58 (47 - 70)	0.90	25 (16 - 37)	32 (20 - 47)	9.5 (1.2 - 30)	0.05	65 (43 - 84)	73 (39 - 94)	58 (28 - 85)	0.47	45 (36 - 54)	46 (30 - 63)	45 (34 - 55)	0.90
Reporting treatment for diabetes (n)	NA	NA	NA		41	18	23		54	11	43		4	3	1		7	4	3		46	14	32	
Reporting treatment for diabetes (%)	NA	NA	NA		75 (61 - 85)	82 (60 - 95)	70 (51 - 84)	0.31	89 (78 - 95)	69 (41 - 89)	96 (85 - 100)	<0.01	22 (6.4 - 48)	19 (4 - 46)	50 (1.3 - 99)	0.32	47 (21 - 73)	50 (16 - 84)	43 (9.9 - 82)	0.78	78 (65 - 88)	82 (57 - 96)	76 (61 - 88)	0.60
Diabetes controlled (n)	NA	NA	NA		13	5	8		25	4	21		2	1	1		4	3	1		14	6	8	
Diabetes controlled (%)	NA	NA	NA		32 (18 - 48)	28 (9.7 - 54)	35 (16 - 57)	0.63	46 (33 - 60)	36 (11 - 69)	49 (33 - 65)	0.46	50 (6.8 - 93)	33 (0.8 - 91)	100 (-)	0.68	57 (18 - 90)	75 (19 - 99)	33 (0.8 - 91)	0.27	30 (18 - 46)	43 (18 - 71)	25 (12 - 43)	0.23

T: total, M:men, W:women; prevalences are given as estimates and 95% confidence intervals. p value for men vs women and calculated using chi-squared or Fisher's exact test. NA-not applicable as these data were not collected

Table S3. Factors associated with odds of having diabetes across three sub-Saharan African sites with high HIV prevalence (Agincourt, Dikgale & Nairobi)[1]

	Odds ratio	95% confidence interval	p value
Age	1.1	1.0-1.1	<0.01
Sex			
Women	reference		
Men	0.8	0.5-1.2	0.21
Marital status			
Currently married or cohabitating	reference		
Never marrried or cohabitating	1.2	0.8-1.8	0.37
Previously married	1.0	0.8-1.4	0.91
Educational attainment			
No formal education	reference		
Primary education	1.5	1.0-2.2	0.07
Secondary education	1.2	0.8-1.9	0.44
Tertiary education	1.2	0.6-2.6	0.60
Employment status			
Unemployed	reference		
Employed	1.2	0.9-1.6	0.19
Smoking status			
No history of smoking	reference		
Current smoker	0.6	0.4-1.1	0.08
History of hypertension			
No	reference		
Yes	2.0	1.5-2.6	<0.01
HIV status			
Negative	reference		
Positive	0.5	0.4-0.8	<0.01
Family history of diabetes			
No	reference		
Yes	3.6	2.8-4.7	<0.01
Physical activity categories			
Absent	reference		
Insufficient	1.4	0.7-3.0	0.33
Sufficient	1.1	0.6-2.0	0.73
Hip circumference	1.0	1.0-1.0	<0.01
Visceral fat	1.2	1.1-1.2	<0.01
Subcutaneous fat	1.3	1.1-1.4	<0.01

[1]3929 participants were included in the analysis

Table S4. Factors associated with odds of having diabetes across two sub-Saharan African sites with low HIV prevalence (Navrongo & Nanoro)[1]

	Odds ratio	95% confidence interval	p value
Age	1.0	1.0-1.1	0.18
Sex			
Women	reference		
Men	1.9	1.1-3.3	0.03
Marital status			
Currently married or cohabitating	reference		
Never married or cohabitating	1.8	0.2-14.2	0.58
Previously married	1.2	0.6-2.3	0.68
Educational attainment			
No formal education	reference		
Primary education	0.5	0.2-1.2	0.12
Secondary education	0.9	0.4-2.5	0.91
Tertiary education	3.7	1.0-13.9	0.05
Employment status			
Unemployed	reference		
Employed	1.8	0.8-3.9	0.13
Smoking status			
No history of smoking	reference		
Current smoker	0.9	0.3-2.6	0.79
History of hypertension			
No	reference		
Yes	1.2	0.7-2.1	0.50
HIV status			
Negative	reference		
Positive	1.7	0.2-13.5	0.63
Family history of diabetes			
No	reference		
Yes	10.4	4.3-25.4	<0.01
Physical activity categories			
Absent	reference		
Insufficient	0.5	0.1-1.7	0.23
Sufficient	0.5	0.3-0.8	0.01
Hip circumference	1.0	1.0-1.1	0.02
Visceral fat	1.2	1.0-1.4	0.14
Subcutaneous fat	1.1	0.7-1.9	0.72

[1]3496 participants were included in the analysis

Table S5. Factors associated with awareness in high HIV prevalence sites (Agincourt, Dikgale, Nairobi & Soweto)[1]

	Odds Ratio	95% confidence interval	p value
Age	1.0	1.0-1.1	0.09
Sex			
Women	reference		
Men	1.0	0.6-1.6	0.85
Marital status			
Currently married or cohabitating	reference		
Never married or cohabitating	1.0	0.5-2.1	0.93
Previously married	0.9	0.5-1.4	0.60
Educational attainment			
No formal education	reference		
Primary education	1.1	0.5-2.3	0.86
Secondary education	1.4	0.7-3.2	0.37
Tertiary education	1.2	0.4-3.9	0.79
Employment status			
Unemployed	reference		
Employed	0.8	0.5-1.2	0.20
History of hypertension			
No	reference		
Yes	1.9	1.2-2.9	0.01
HIV status			
Negative	reference		
Positive	2.1	1.1-4.0	0.03
Body mass index	1.0	0.9-1.0	0.17

[1]397 participants were included in the analysis

STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

	Item No	Recommendation	Page No
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	3
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	3-4
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	6-7
Objectives	3	State specific objectives, including any prespecified hypotheses	7
Methods			
Study design	4	Present key elements of study design early in the paper	7-8
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	7-8
Participants	6	(*a*) Give the eligibility criteria, and the sources and methods of selection of participants	7-8
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	8-10
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	8-10
Bias	9	Describe any efforts to address potential sources of bias	10-11
Study size	10	Explain how the study size was arrived at	7-8
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	10-12
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	10-12
		(*b*) Describe any methods used to examine subgroups and interactions	10-12
		(*c*) Explain how missing data were addressed	12
		(*d*) If applicable, describe analytical methods taking account of sampling strategy	n/a
		(*e*) Describe any sensitivity analyses	11-12
Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	12,15
		(b) Give reasons for non-participation at each stage	15
		(c) Consider use of a flow diagram	
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	12-14
		(b) Indicate number of participants with missing data for each variable of interest	13-15, 17, 18
Outcome data	15*	Report numbers of outcome events or summary measures	15

Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	16
		(*b*) Report category boundaries when continuous variables were categorized	n/a
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	n/a
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	16
Discussion			
Key results	18	Summarise key results with reference to study objectives	18
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	20-21
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	18-22
Generalisability	21	Discuss the generalisability (external validity) of the study results	21
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	23-24

*Give information separately for exposed and unexposed groups.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.