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CARE DELIVERY

Factors associated with potential over- and undertreatment of hyperglycaemia and annual measurement of HbA_{1c} in type 2 diabetes in norwegian general practice

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Abstract

Aims: To identify individual and general practitioner (GP) characteristics associated with potential over- and undertreatment of hyperglycaemia in type 2 diabetes and with HbA_{1c} not being measured.

Methods: A cross-sectional study that included 10233 individuals with type 2 diabetes attending 282 GPs. Individuals with an HbA_{1c} measurement during the last 15 months were categorized as potentially overtreated if they were prescribed a sulphonylurea and/or insulin when the HbA_{1c} was less than 53 mmol/mol (7%) when aged over 75 years or less than 48 mmol/mol (6.5%) when aged between 65 and 75 years. Potential undertreatment was defined as age less than 60 years and $HbA_{1c} > 64$ mmol/mol (8.0%) or $HbA_{1c} > 69$ mmol/mol (8.5%) and treated with lifestyle modification and/or monotherapy. We used multilevel binary and multinominal logistic regression models to examine associations.

Results: Overall, 4.1% were potentially overtreated, 7.8% were potentially undertreated and 11% did not have HbA_{1c} measured. Characteristics associated with potential overtreatment were as follows: long diabetes duration, prescribed antihypertensive medication, cardiovascular disease and renal failure. Potential undertreatment was associated with male gender, non-western origin and low educational level. Characteristics associated with not having an HbA_{1c} measurement performed were

male gender, age < 50 years and cardiovascular diseases. GP specialist status and GPs' use of a Noklus diabetes application reduced the risk of not having an HbA_{1c} measurement performed.

Conclusion: Potential overtreatment in elderly individuals with type 2 diabetes was relatively low. Nevertheless, appropriate de-intensification or intensification of treatment and regular HbA_{1c} measurement in identified subgroups is warranted.

KEYWORDS

family medicine, general practice, HbA_{1c}, overtreatment, type 2 diabetes, undertreatment

1 | INTRODUCTION

Early, intensive and multifactorial treatment of type 2 diabetes reduces vascular complications.[1,2] However, several observational studies have repeatedly confirmed suboptimal glycaemic control in a considerable proportion of individuals with type 2 diabetes.[3–5] The GUIDANCE study with data from eight European countries reported that only 54% achieved an HbA_{1c} target of less than 53 mmol/mol (7.0%).[3] Individual factors like ability to adhere to recommended lifestyle modification and/or medication, comorbidities and healthcare provider and/or healthcare system factors (i.e. workload and health expenses) may impact the achievement of treatment targets and clinical outcomes.[6–8]

On the other hand, serious hypoglycaemia and increased mortality caused by intensive treatment have been increasingly documented[9–11] and more personalized HbA_{1c} targets have been promoted.[12] The Norwegian clinical Guidelines for Diabetes recommend an HbA_{1c} level of approximately 53 mmol/mol (7.0%) as a treatment target in most individuals with type 2 diabetes.[13] The American Diabetes Association and the European Association for the Study of Diabetes recommend doctors to consider de-intensification when HbA_{1c} is below 48mmol/mol (6.5%) or substantially below the personalized treatment target, and to consider two or more glucose-lowering agents when HbA_{1c} is 17 mmol/mol (1.5%) or more above the personalized treatment target.[14] The concept of quaternary prevention, that is, actions taken to identify individuals at risk for over-medicalization and to protect them from medical interventions, highlights the delicate balance between possible benefit and harm.[15]

In Norway, most individuals with type 2 diabetes are cared for by general practitioners (GPs).[13] Healthcare services are state-funded in Norway and all citizens are entitled to be registered with a specific GP. In this study of individuals with type 2 diabetes, we aimed to identify individual and GP characteristics associated with potential over- and undertreatment of hyperglycaemia and characteristics associated with an annual HbA_{1c} measurement not being performed.

What this study has found?

- According to our definitions, 4.1% of individuals with type 2 diabetes were potentially overtreated in Norway and 7.5% were potentially undertreated.
- 12% of those aged over 75 years were prescribed sulphonylurea and/or insulin when the HbA_{1c} was less than 53 mmol/mol (7%).
- Long diabetes duration, prescribed antihypertensive medication, cardiovascular disease and renal failure were associated with overtreatment.
- Male gender, non-western origin and low educational level were associated with undertreatment.
- GP's workload was not associated with over- or undertreatment.
- Being a GP specialist and the GP's use of Noklus diabetes application reduced the risk of an HbA_{1c} measurement not being performed.

2 | PARTICIPANTS AND METHODS

We used data from a large population-based, cross-sectional survey, the ROSA 4 study (Rogaland–Oslo–Salten–Akershus–Hordaland study), assessing the quality of type 2 diabetes care in general practice in Norway in 2014, that is described in detail elsewhere.[16,17] In brief, 106 practices with 367 GPs from urban and rural areas in 5 of Norway's 19 counties were invited to participate in the study, and 77 (73%) practices with 282 (77%) GPs accepted the invitation. All individuals with diabetes cared for by these GPs participated in the study. Results of blood tests and prescription data from 2012 to 2014 were obtained from the electronic health records (EHRs) of all individuals aged ≥18 years with diabetes diagnosis. Research nurses verified the diabetes diagnosis and supplemented the database with information not captured electronically such as smoking habits, diabetes duration and complications by searching the EHRs using relevant keywords.[16,17] In total, 11 428 individuals participated

in the ROSA 4 study. In the present study, we excluded individuals with other diabetes types and those with an unknown country of birth, leaving 10233 individuals with type 2 diabetes in the study (Figure 1). The study was approved by the Regional Ethical Committee (REK 2014/1374, REK Vest).

2.1 | Characteristics of individuals with type 2 diabetes and general practitioners

Individual characteristics included the following: age, gender, diabetes duration, smoking habits, cardiovascular disease (CVD) defined as stroke, angina, myocardial infarction, percutaneous coronary intervention or coronary artery bypass surgery. We used the most recent HbA_{1c} value and the most recent prescriptions of glucose-lowering, antihypertensive and lipid-lowering medication recorded between 1st October 2013 and 31st December 2014. The most recent creatinine/eGFR value between 1st January 2012 and 31st December 2014 was also used. Information about country of birth and educational level was obtained from Statistics Norway. Ethnicity was classified as (1) Westerners (i.e. born in Western Europe and North America) and (2) non-westerners (born in non-western countries). Education was categorized as follows: (1) primary school, (2) secondary school (including sixth form college) and (3) higher education.[18]

Information about GPs characteristics were collected using a study-specific questionnaire: age, gender, GP specialist status (i.e. having completed the specialist education programme for general practice), GPs use of a software tool (Noklus diabetes application) that lists recommended tasks in the annual review and allows the performance of these tasks to be reported to the Norwegian Diabetes Register. The number of individuals with type 2 diabetes cared for by each specific GP was captured from the GPs' EHRs. The total number of individuals on the GP's list was obtained from the Norwegian Health Economics Administration at the time of data collection. A GP workload factor was obtained by dividing the total

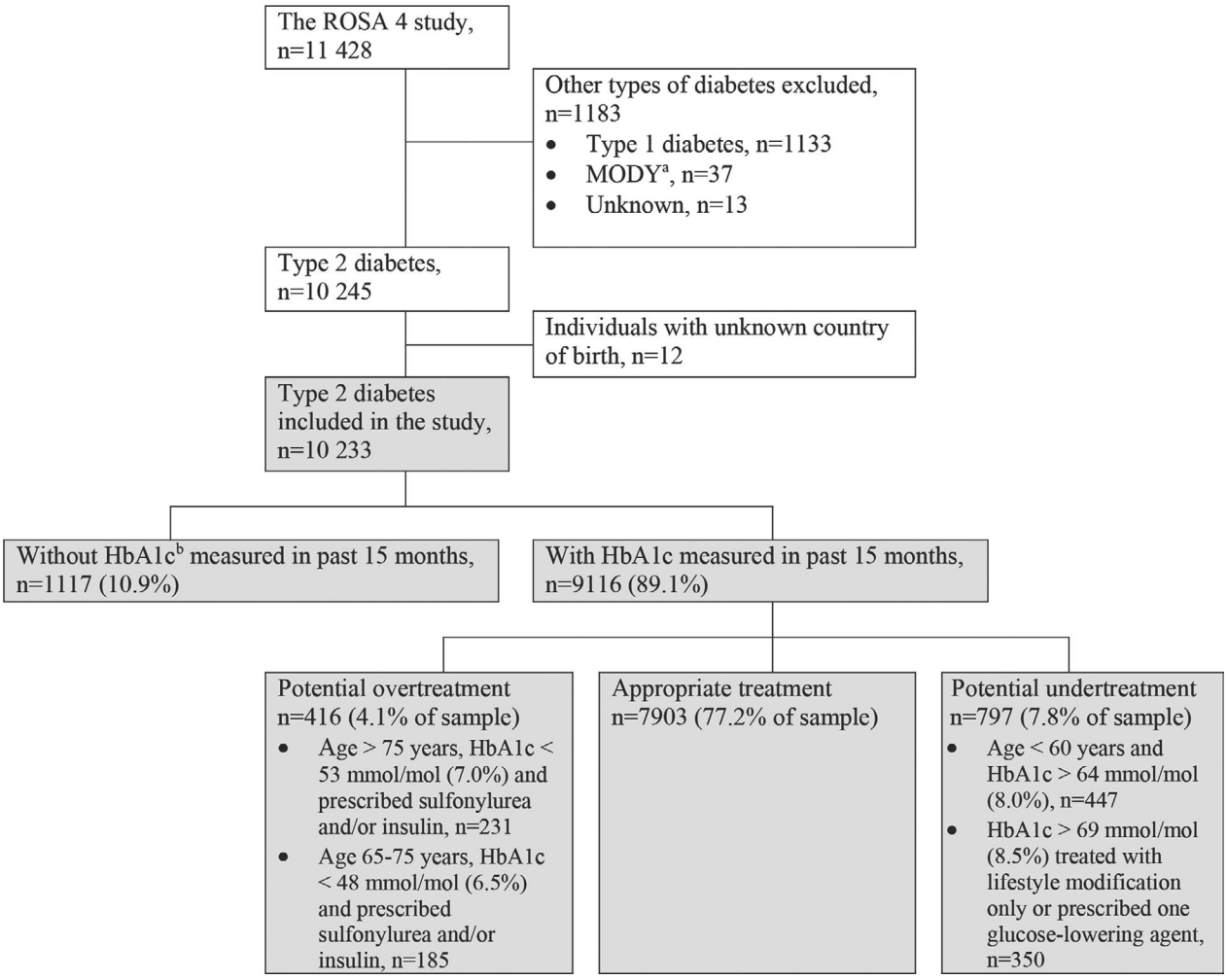

FIGURE 1 Flow chart of individuals with type 2 diabetes included in the study. [a] MODY: maturity onset diabetes of the young. [b] HbA_{1c}: Glycated haemoglobin A1c.

TABLE 1 Characteristics of individuals with type 2 diabetes by HbA_{1c} measurement (n=10233)

Characteristics n (%) or mean (95% CI)	Missing observations n (%)	All n=10233	HbA_{1c} not measured n=1117	HbA_{1c} measured n=9116	*p*
Men		5624 (55.0)	670 (60.0)	4954 (54.3)	0.005
Age, years					
Mean		64.8 (64.5, 65.0)	64.22 (63.5, 65.1)	64.8 (63.47, 65.1)	0.131
<50		1355 (13.2)	193 (17.3)	1162 (12.7)	0.820
50–59		2072 (20.2	222 (19.9)	1850 (20.3)	0.889
60–69		2998 (29.3)	294 (26.3)	2704 (29.7)	0.224
70–79		2411 (23.6)	219 (19.6)	2192 (24.0)	0.144
≥80		1397 (13.7)	189 (16.9)	1208 (13.3)	0.182
Ethnicity					
Westerners		8497 (83.0)	937 (83.9)	7560 (83.0)	0.442
Non-westerners		1736 (17.0)	180 (16.1)	1736 (17.0)	0.730
Education	195 (1.9)				
Primary school		3671 (36.6)	399 (36.2)	3272 (36.6)	0.876
Secondary school		4516 (45.0)	499 (45.2)	4017 (45.0)	0.933
Higher education		1851 (18.4)	205 (18.6)	1646 (18.4)	0.944
Diabetes duration, years	633 (6.2)				
Mean		8.6 (8.5, 8.8)	9.2 (8.7, 9.6)	8.6 (8.4, 8.7)	0.010
<5		3214 (33.5)	327 (33.1)	2887 (33.5)	0.884
5–9		2802 (29.2)	272 (27.5)	2530 (29.4)	0.513
10–14		1855 (19.3)	191 (19.3)	1664 (19.3)	1.000
≥15		1729 (18.0)	198 (20.0)	1531 (17.2)	0.449
Current smoking	17 (0.2)	1824 (17.9)	195 (17.6)	1629 (17.9)	0.918
Medication					
Glucose-lowering		6984 (68.2)	534 (48.6)	6441 (70.7)	<0.001
Antihypertensive		6689 (65.4)	500 (44.8)	6189 (67.9)	<0.001
Lipid-lowering		5541 (54.1)	385 (34.5)	5156 (56.6)	<0.001
Cardiovascular disease[a]	45 (0.4)	2801 (27.5)	310 (27.9)	2491 (27.4)	0.852
eGFR < 45 ml/min/1.73 m^2	538 (5.3)	635 (6.5)	76 (9.4)	559 (6.3)	0.550
County of residence					
Oslo		2526 (24.7)	219 (19.6)	2307 (25.3)	0.062
Akershus		1412 (13.8)	159 (14.2)	1253 (13.7)	0.864
Hordaland		1608 (15.7)	223 (20.0)	1385 (15.2)	0.069
Nordland		2792 (27.3)	376 (33.7)	2416 (26.5)	0.004
Rogaland		1895 (18.5)	140 (12.5)	1755 (19.3)	0.047

Chi-square tests were applied to compare group differences in proportions between those with and without HbA_{1c} measurement. One-way between-groups ANOVA with post-hoc tests were applied to compare group differences in means.

[a]Cardiovascular disease included coronary heart disease and/or stroke and/or arterial surgery.

number of individuals on the GP's list by the number of days per week that the GP had clinical practice.

2.2 | Outcomes

After consideration of the Norwegian Guidelines at the time of the study,[13] recommendations from the American Diabetes Association and the European Association for the Study of Diabetes,[13,14] we pragmatically defined our outcomes as potential over- or undertreatment if the following criteria were met:

Potential overtreatment: A sulphonylurea and/or insulin was prescribed when either HbA_{1c} was less than 53 mmol/mol (7%) in a patient aged over 75 years, or HbA_{1c} was less than 48 mmol/mol (6.5%) in a patient aged between 65 and 75 years.

Potential undertreatment: HbA_{1c} greater than 64 mmol/mol (8.0%) and age less than 60 years or HbA_{1c} greater than 69 mmol/mol (8.5%) and treated with lifestyle modification and/or prescribed one glucose-lowering agent only. All others were considered to be appropriately treated.

We considered the GPs' annual performance of HbA_{1c} measurement as satisfactory if at least one HbA_{1c} measurement was recorded during the last 15 months.

2.3 | Statistical analyses

Descriptive statistics including frequencies, mean and Chi-square tests and the one-way ANOVA tests with post-hoc tests were used to compare differences between the groups as appropriate.

Missing data (diabetes duration: 633 [6.2%], eGFR value: 538 [5.3%], education level: 195 [1.9%], CVD: 45 [0.4%] and smoking status: 17 [0.2%]) were imputed to reduce bias in the estimates, using multiple imputation by chained equations, allowing for the multilevel structure of the data.[19] The imputation included all variables in the main models (i.e. available individual data included in the model were used for estimation of missing value). We produced 10 imputed datasets. Three-level regression models were used to account for individuals' data (level 1) that were nested within GPs (level 2) who were nested within practices (level 3). Multilevel multinominal logistic regression models with the appropriate treatment group as reference were used to examine associations between individual and GP characteristics and potential under- and overtreatment. Multilevel binary logistic regression models with HbA_{1c} measured or not as the dependent variable were run to examine the associations with individual and GP characteristics. Multilevel binary logistic regression models were used to estimate the proportions being prescribed glucose-lowering medication, adjusted for individual-level and GP-level characteristics. As explanatory variables, we included 11 individual-level variables and five GP-level variables in regression models.

We estimated the proportion of variance explained by each full model from the variance of the linear predictor for the fixed portion of the model and from the estimated random intercepts variances. Intra-cluster correlation coefficients were used to estimate the proportion of the outcome or residual variations attributed to individuals, GPs and practices.

Sensitivity analyses included multilevel binary logistic regression analysis and multilevel multinomial logistic regression analysis of complete cases. The significance level was set at < 0.01. The analyses were performed with SPSS Statistics 24 and StataSE 15-16.

3 | RESULTS

Overall, 416 (4.1%) individuals with type 2 diabetes were potentially overtreated (all were over 65 years), 797 (7.8%) of all age groups were potentially undertreated (Figure 1). Furthermore, 1117 (11%) had no recorded annual HbA_{1c} measurement. Among 1902 individuals aged over 75 years with recorded prescriptions for a sulphonylurea or insulin, 231 (12%) had $HbA_{1c} < 53$mmol/mol (7.0%), 108 (5.7%) had $HbA_{1c} < 48$ mmol/mol (6.5%) while 69 (3.6%) met the criteria for undertreatment (results not shown).

Characteristics of the study population stratified by HbA_{1c} measurement and by treatment status are presented in Tables 1 and 2. Compared with individuals appropriately treated, those who were overtreated had longer mean diabetes duration (13 years vs. 8.2 years), a higher proportion were prescribed glucose-lowering or antihypertensive medication, and had CVD or an eGFR < 45 ml/min/1.73 m^2. Compared with individuals appropriately treated, those undertreated were younger (mean age 55 years vs. 65 years), had longer mean diabetes duration (9.4 years vs. 8.2 years), a higher proportion were men (62% vs. 54%), non-westerners (34% vs. 16%) and were prescribed glucose-lowering medication (89% vs. 67%) while a lower proportion were prescribed antihypertensive medication (55% vs. 68%) (Table 2). Compared with individuals with an HbA_{1c} measurement, the group without an HbA_{1c} measurement had a higher proportion of men (60% vs. 54%), a lower proportion were prescribed glucose-lowering medication (49% vs. 71%), anti-hypertensive medication (45% vs. 68%) and lipid-lowering medication (35% vs. 57%) (Table 1). Characteristics of the GPs are shown in Table S1.

As the prescription pattern is an integral part in the definitions of over- and undertreatment, we found in the potentially overtreated group, 65% were prescribed sulphonylurea, 32% were prescribed insulin and 2.9% were prescribed both sulphonylurea and insulin. In the potentially undertreated group, 11% were treated with lifestyle modification only and 43% were prescribed one glucose-lowering agent. Prescriptions of glucose-lowering medication by treatment status after adjustments for confounders are shown in Figure 2a,b.

3.1 | Factors associated with potential over- and undertreatment

Characteristics associated with potential overtreatment were diabetes duration ≥ 15 years, prescribed antihypertensive medication, presence of CVD or eGFR < 45 ml/min/1.73 m^2, whereas non-western origin and diabetes duration 5–10 years reduced the risk, after adjustments for all factors in Table 3.

TABLE 2 Characteristics of individuals with type 2 diabetes with HbA_{1c} measured by treatment status (n=9116)

Characteristics n (%) or mean	Missing observations n (%)	Potential overtreatment n=416	Appropriate treatment n=7903	Potential undertreatment n=797	P[a]	P[b]
Men		233 (56.0)	4230 (53.5)	492 (61.7)	0.834	0.007
Age, years						
Mean		76.8 (76.1, 77.5)	65.2 (64.9, 65.5)	55.1 (54.2, 56.0)	<0.001	<0.001
<50		0 (0.0)	903 (11.4)	259 (32.5)		<0.001
50–59		0 (0.0)	1505 (19.0)	346 (43.4)		<0.001
60–69		82 (19.7)	2537 (32.1)	84 (10.5)	0.018	<0.001
70–79		186 (44.7)	1946 (24.6)	60 (7.5)	<0.001	0.002
≥80		148 (35.6)	1012 (12.8)	48 (6.0)	<0.001	0.164
Ethnicity						
Westerners		397 (95.4)	6651 (84.2)	514 (64.5)	<0.001	<0.001
Non-westerners		19 (4.6)	1252 (15.8)	283 (35.5)	0.182	<0.001
Education	180 (2.0)					
Primary school		155 (37.6)	2765 (35.6)	352 (46.2)	0.613	<0.001
Secondary school		202 (49.0)	3536 (45.6)	279 (36.6)	0.346	0.004
Higher education		55 (13.3)	1460 (18.8)	131 (17.2)	0.303	0.653
Diabetes duration, years	504 (5.5)					
Mean		13.2 (12.5, 14.0)	8.2 (8.1, 8.4)	9.4 (8.9, 10.0)	<0.001	<0.001
<5		52 (13.5)	2614 (35.0)	222 (29.3)	0.001	0.086
5–9		76 (19.7)	2224 (29.8)	230 (30.4)	0.058	0.187
10–14		94 (24.4)	1423 (19.0)	147 (19.4)	0.199	0.906
≥15		164 (42.5)	1209 (16.2)	158 (20.9)	<0.001	0.137
Current smoking	11 (0.1)	58 (10.0)	1398 (17.7)	174 (22.0)	0.130	0.165
Medication						
Glucose-lowering		416 (100.0)	5316 (67.3)	708 (88.8)	<0.001	<0.001
Antihypertensive		356 (85.6)	5396 (68.3)	436 (54.7)	<0.001	<0.001
Lipid-lowering		262 (63.0)	4488 (56.8)	406 (50.9)	0.049	0.022
Cardiovascular disease	39 (0.4)	173 (41.9)	2156 (27.4)	163 (20.6)	<0.001	0.059
eGFR < 45 ml/min/1.73 m^2	228 (2.5)	75 (18.2)	447 (5.8)	37 (4.9)	<0.001	0.821
County of residence						
Oslo		92 (22.1)	1953 (24.7)	261 (32.7)	0.571	0.005
Akershus		53 (12.7)	1099 (13.9)	101 (12.7)	0.805	0.738
Hordaland		72 (17.3)	1224 (15.5)	90 (11.3)	0.682	0.284
Nordland		115 (27.6)	2098 (26.5)	203 (25.5)	0.795	0.758
Rogaland		84 (20.2)	1529 (19.3)	142 (17.8)	0.839	0.664

Chi-square tests were applied to compare group differences in proportions.

One-way between-groups ANOVA with post-hoc tests were applied to compare group differences in means.

[a]Differences between the potential overtreatment group and the appropriate treatment group.

[b]Differences between the potential undertreatment group and the appropriate treatment group.

Characteristics associated with potential undertreatment were male gender, non-western origin and current smoking, while characteristics reducing the odds of potential undertreatment were higher level of education, diabetes duration 5–10 years, being prescribed antihypertensive medication and the presence of CVD.

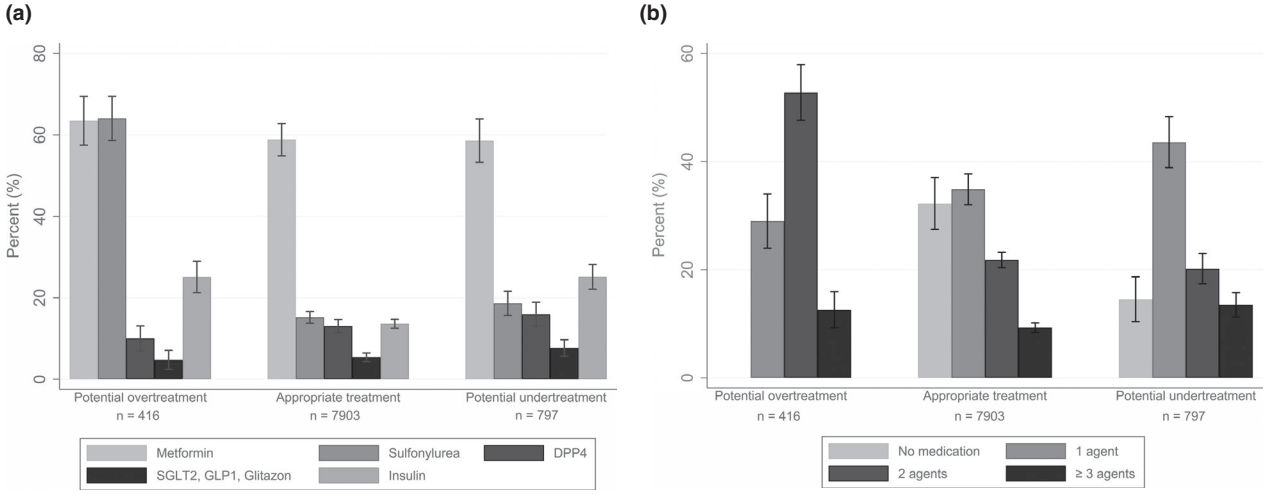

FIGURE 2 (a) Glucose-lowering agents by treatment status[a] (n=9116)[b]. [a] Potential overtreatment if prescriptions of a sulphonylurea and/or insulin when HbA_{1c} < 53 mmol/mol (7.0%) and age > 75 years or when HbA_{1c} < 48 mmol/mol (6.5%) and age 65–75 years. Potential undertreatment if age <60 years and HbA_{1c} > 64 mmol/mol (8.0%) or HbA_{1c} > 69 mmol/mol (8.5%) treated with diet only or prescribed one glucose-lowering agent. All others are considered appropriately treated. [b] Missing data in the included individuals were imputed using multiple imputation by chained equations. Data are adjusted proportions (95%CI). Multilevel binary logistic regression models were used to estimate the proportions being prescribed glucose-lowering medication, adjusted for individual-level characteristics (age, gender, ethnicity, diabetes duration, education, current smoking, presence of cardiovascular disease, eGFR < 45 ml/min/1.73 m^2, prescriptions of antihypertensive, lipid-lowering medication and county of residence) and GP-level characteristics (gender, specialist status, number of individuals with diabetes on GPs list, work load and use of Noklus diabetes application). DPP4: Dipeptidyl peptidase-4 inhibitor, SGLT2: Sodium-glucose Cotransporter-2 inhibitors, GLP1: Glucagon-like peptide-1 receptor agonists. Types of agents add up to > 100 % because many individuals were prescribed more than one type of agents. (b) Number of glucose-lowering agents by treatment status[a] (n=9116)[b]. [a] Potential overtreatment if prescriptions of a sulphonylurea and/or insulin when HbA_{1c} < 53 mmol/mol (7.0%) and age > 75 years or when HbA_{1c} < 48 mmol/mol (6.5%) and age 65–75 years. Potential undertreatment if age < 60 years and HbA_{1c} > 64 mmol/mol (8.0%) or HbA_{1c} > 69 mmol/mol (8.5%) treated with diet only or prescribed one glucose-lowering agent. All others are considered appropriately treated.[b] Missing data in the included individuals were imputed using multiple imputation by chained equations. Data are adjusted proportions (95%CI). Multilevel binary logistic regression models were used to estimate the proportions being prescribed glucose-lowering medication, adjusted for individual-level characteristics (age, gender, ethnicity, diabetes duration, education, current smoking, presence of cardiovascular disease, eGFR < 45 ml/min/1.73 m^2, prescriptions of antihypertensive, lipid-lowering medication and county of residence) and GP-level characteristics (gender, specialist status, number of individuals with diabetes on GPs list, work load and use of Noklus diabetes application).

3.2 | Factors associated with not having an HbA_{1c} measurement performed

After adjustment for all factors in Table 4, the individual characteristics associated with not having an HbA_{1c} measurement performed were as follows: male gender, age less than 50 years, diabetes duration more than 5 years and presence of CVD. Individual characteristics that reduced the odds of not having an HbA_{1c} measurement performed were a recorded prescription of glucose-lowering, antihypertensive or lipid-lowering medication, GPs specialist status and GPs use of a Noklus diabetes application.

3.3 | Explained variance

Differences between GPs and practices accounted for 11% and 15%, respectively, of the variability in potential over- and undertreatment. After adjustment for individual variables, the fixed and random effects of the full model explained 4% and 22% of the total variation.

Differences between GPs and practices explained 15% and 9% of the variability in not having an HbA_{1c} measurement performed. After adjustment, the fixed and random effects explained 3% and 21% of the variation.

4 | DISCUSSION

Using our definitions, 4.1% of individuals with type 2 diabetes were potentially overtreated (12% of those aged over 75 years), 7.8% were potentially undertreated and 11% did not have an annual HbA_{1c} measurement performed. Long diabetes duration, prescribed antihypertensive medication, presence of CVD and renal failure were independently associated with potential overtreatment, whereas male gender, non-western origin, low education level and current smoking were independently associated with potential undertreatment.

TABLE 3 Characteristics of individuals with type 2 diabetes and general practitioners with adjusted odd ratios for potential over- and undertreatment in those with an HbA_{1c} measurement (n=9116)[a]

	Potential overtreatment[b] n=416		Potential undertreatment[c] n=797	
Individual characteristics	**OR (95% CI)**	**P**	**OR (95% CI)**	***P***
Men	1.14 (0.92, 1.41)	0.235	1.62 (1.38, 1.90)	<0.001
Non-westerners	0.29 (0.18, 0.47)	<0.001	2.57 (2.12, 3.12)	<0.001
Education				
Primary school	1		1	
Secondary school	1.01 (0.80, 1.27)	0.939	0.72 (0.61, 0.86)	<0.001
Higher education	0.81 (0.58, 1.13)	0.212	0.69 (0.56, 0.87)	0.001
Diabetes duration, years				
<5	1		1	
5–9	0.67 (0.54, 0.83)	<0.001	0.84 (0.75, 0.96)	0.008
10–14	1.08 (0.89, 1.31)	0.451	1.13 (1.00, 1.27)	0.049
≥15	1.91 (1.59, 2.31)	<0.001	1.19 (1.04, 1.36)	0.012
Current smoking	0.87 (0.65, 1.17)	0.364	1.38 (1.15, 1.67)	0.001
Medication				
Antihypertensive	1.92 (1.42, 2.59)	<0.001	0.66 (0.56, 0.78)	<0.001
Lipid-lowering	0.85 (0.68, 1.07)	0.168	0.95 (0.80, 1.12)	0.519
Cardiovascular disease[d]	1.36 (1.09, 1.70)	0.007	0.70 (0.58, 0.86)	<0.001
eGFR < 45 ml/min/1.73 m^2	2.01 (1.51, 2.68)	<0.001	1.04 (0.73, 1.49)	0.832
County of residence				
Oslo	1		1	
Akershus	1.04 (0.68, 1.61)	0.846	0.83 (0.60, 1.17)	0.290
Hordaland	1.04 (0.69, 1.57)	0.831	0.78 (0.55, 1.11)	0.165
Nordland	0.87 (0.61, 1.25)	0.462	1.16 (0.88, 1.54)	0.295
Rogaland	1.01 (0.68, 1.49)	0.970	0.87 (0.64, 1.18)	0.374
General practitioner (GP) characteristics				
Men	1.15 (0.87, 1.52)	0.337	0.94 (0.76, 1.16)	0.539
GP specialist	0.84 (0.64, 1.11)	0.216	0.93 (0.75, 1.15)	0.509
No. individuals with diabetes on GPs list				
<25	1		1	
25–49	0.93 (0.67, 1.29)	0.690	1.08 (0.84, 1.38)	0.293
≥50	0.90 (0.60, 1.35)	0.510	1.05 (0.76, 1.45)	0.211
Workload factor[e]				
<250	1		1	
250–350	1.09 (0.71, 1.68)	0.660	0.85 (0.63, 1.15)	0.558
>350	1.17 (0.74, 1.86)	0.614	0.81 (0.58, 1.13)	0.748
Use of Noklus diabetes application[f]	1.05 (0.80, 1.37)	0.722	0.79 (0.63, 0.98)	0.033

Multilevel multinomial logistic regression models were used to compare the differences between the potential overtreatment group and the potential undertreatment group with the appropriate treatment group as reference adjusted for all variables shown in table. All models include random intercepts for practices and for general practitioners within practices.

[a]Missing data were imputed using multiple imputation by chained equations.

[b]Potential overtreatment if prescriptions of a sulphonylurea and/or insulin when HbA_{1c} < 53 mmol/mol (7.0%) and age > 75 years or when HbA_{1c} < 48 mmol/mol (6.5%) and age 65–75 years.

[c]Potential undertreatment if age < 60 years and HbA_{1c} > 64 mmol/mol (8.0%) or HbA_{1c} > 69 mmol/mol (8.5%) treated with diet only or prescribed one glucose-lowering agent.

[d]Cardiovascular disease included coronary heart disease and/or stroke and/or arterial surgery.

[e]The variable reflects GPs' workload and is obtained by dividing the total number of individuals on the GP's list by the number of days per week the GP has clinical practice.

[f]General practitioner defined as a user of the Noklus diabetes application if used in > 40% of people with diabetes on the GP's list.

TABLE 4 Characteristics of individuals with type 2 diabetes and general practitioners with adjusted odd ratios for not having an HbA_{1c} measurement performed (n=10 233)[a]

Individual characteristics	OR (95% CI)	*p*
Men	1.30 (1.13, 1.51)	<0.001
Age, years		
<50	1.39 (1.11, 1.74)	0.005
50–59	1.16 (0.95, 1.42)	0.144
60–69	1	
70–79	0.82 (0.66, 1.00)	0.055
≥80	1.03 (0.81, 1.31)	0.792
Non-westerners	0.90 (0.72, 1.12)	0.348
Education		
Primary school	1	
Secondary school	1.05 (0.89, 1.23)	0.573
Higher education	1.00 (0.82, 1.23)	0.971
Diabetes duration, years		
<5	1	
5–9	1.41 (1.18, 1.70)	<0.001
10–14	1.78 (1.43, 2.20)	<0.001
≥15	2.25 (1.76, 2.88)	<0.001
Current smoking	1.01 (0.84, 1.21)	0.945
Medication		
Glucose-lowering	0.34 (0.29, 0.40)	<0.001
Antihypertensive	0.47 (0.40, 0.55)	<0.001
Lipid-lowering	0.61 (0.52, 0.71)	<0.001
Cardiovascular disease[b]	1.31 (1.10, 1.55)	0.003
eGFR < 45 ml/min/1.73 m^2	1.35 (1.00, 1.82)	0.049
County of residence		
Oslo	1	
Akershus	1.69 (0.93, 3.05)	0.085
Hordaland	2.30 (1.27, 4.15)	0.006
Nordland	2.34 (1.43, 3.81)	0.001
Rogaland	1.21 (0.71, 2.07)	0.478
General practitioner (GP) characteristics		
Men	1.21 (0.97, 1.52)	0.089
GP specialist	0.65 (0.51, 0.83)	<0.001
No. individuals with diabetes on GPs list		
<25	1	
25–49	0.95 (0.69, 1.31)	0.772
≥50	0.92 (0.64, 1.34)	0.677
Workload factor[c]		
<250	1	
250–350	1.06 (0.78, 1.45)	0.696
>350	1.25 (0.86, 1.81)	0.248
Use of Noklus diabetes application[d]	0.23 (0.18, 0.31)	<0.001

Multilevel binary logistic regression models were used to compare the differences between those without an HbA_{1c} measurement (n=1117) and those with an HbA_{1c} measurement (n=9116) as reference. Multivariable results were adjusted for all variables shown in table. All models include random intercepts for practices and for general practitioners within practices.

[a]Missing data in the included individuals were imputed using multiple imputation by chained equations.

[b]Cardiovascular disease included coronary heart disease and/or stroke and/or arterial surgery.

[c]The variable reflects GPs' workload and is obtained by dividing the total number of individuals on the GP's list by the number of days per week the GP has clinical practice.

[d]General practitioner defined as a user of the Noklus diabetes application if used in > 40% of people with diabetes on the GP's list.

Male gender, young age, long diabetes duration and presence of CVD increased the odds of not having an HbA_{1c} measurement performed. No GP characteristics were found to be associated with potential over- or undertreatment, whereas GP specialist status and GPs use of a Noklus diabetes application reduced the risk of not having HbA_{1c} measured.

Our definition of overtreatment focused on individuals who are most vulnerable for the adverse effects of hypoglycaemia. We found that potential overtreatment, particularly for those aged over 75 years was relatively low (12%), compared with two recent US studies reporting that 21% and 45% of those aged over 75 years with an $HbA_{1c} \leq 53$ mmol/mol (7.0%) were treated with a sulphonylurea or insulin.[20,21] The latter study included individuals with type 2 diabetes receiving two or more visits at an academic diabetes centre.[21] Another US study found that 62% of elderly individuals aged over 65 years with an $HbA_{1c} < 53$mmol/mol (7.0%) were prescribed sulphonylureas or insulin.[22] The GUIDANCE study, which included individuals with type 2 diabetes in ambulatory care (74% from primary care and 26% from specialist care), reported that 44.7% of those aged over 65 years had an $HbA_{1c} \leq 53$ mmol/mol (7%) and were treated with sulphonylureas or insulin.[23] Differences in definition of overtreatment, the study settings and healthcare systems may partly explain the observed differences. Our finding of an association between the presence of CVD and overtreatment suggests that de-intensification of glucose-lowering medication among individuals older than 65 years ought to be considered.[24]

We found indications of clinical inertia with delayed initiating or intensifying glucose-lowering treatment.[5] Reasons for clinical inertia are complex and may be attributed to barriers at individual, GP or system level.[6,25] The Norwegian state-funded healthcare system including financial incentives for prolonged consultations when appropriate, and low medical expenses for

individuals with chronical conditions, may have contributed to relative low level of undertreatment. However, younger individuals may benefit from more intensive glucose-lowering therapy as suboptimal glycaemic control increases their risk of complication during an expected longer life span.[26] Language barriers and/or low health literacy among non-westerners might lead to a lack of adherence with prescribed medication and undertreatment.[6,27] Similarly, lack of ability to adhere to recommended lifestyle modification and/or difficulties in coping with complex treatment regimens among those with a low level of educational might explain the observed association.[6,28] Our finding that male gender was associated with undertreatment is in line with another study of gender differences in adherence to prescribed glucose-lowering medication.[29] Interestingly, only a small proportion of those aged over 75 years were undertreated, reflecting individualization of treatment in most elderly healthy individuals.[24] The state-funded healthcare system with an average list size of 1150 persons per GP may explain our finding of no association between a GP's workload and undertreatment while work pressure and time limitations in primary care were found to be a reason for clinical inertia in UK.[6] GP specialist status had little effect on undertreatment. A possible explanation might be that a large proportion of non-specialists intend to become specialists and could be undergoing vocational training.

Annual HbA_{1c} measurement and personalized treatment intensification in individuals with elevated HbA_{1c} are associated with better glycaemic control, although performance of HbA_{1c} measurement alone does not necessarily lead to better clinical/intermediate outcomes.[30] The GUIDANCE study reported the overall proportion with an HbA_{1c} measurement performed in the last 12 months to be 98%, with little variation between countries, somewhat higher than in our study.[3] We have previously reported no improvements in performance of HbA_{1c} measurement from 2005 to 2014,[16] but for the first time, we have identified factors associated with not having an HbA_{1c} measurement performed. In some individuals with CVD and/or additional co-morbidities such as terminal illness, severe stroke or short life expectancy, treatment of these conditions are likely given a higher priority during the consultation than HbA_{1c} measurement. Furthermore, some of these individuals might only attend secondary care or be residents at nursing homes, which would lead to the HbA_{1c} test results not being registered in GP records during the actual period. The Noklus diabetes application reminds GPs on recommend tasks and may have contribute to improve the performance of HbA_{1c} measurement.

4.1 | Strengths and limitations

Our study has several strengths. It is a large population-based study conducted in general practice with high GP participation rates. The study included practices in both urban and rural districts and the study population is considered to be fairly representative for the type 2 diabetes population in Norway.[17] Experienced research nurses verified the diabetes diagnosis and supplemented the database with information not captured electronically, thereby increasing the internal validity. We collected information about patients' ethnicity and education levels through linkage with data from national registries. We obtained relevant information about 99% of the participating GPs from a questionnaire.

Our definitions of potential over- and undertreatment were essentially pragmatic decisions based on the available data, and we lack information about hypoglycaemic episodes and individual lifestyle. Due to the cross-sectional design, the individual glycaemic control was based upon the most recent HbA_{1c} value and the glucose-lowering medication was based on the most recent prescriptions, we were therefore not able to assess changes in prescriptions of glucose-lowering medication in relation to the actual HbA_{1c} level. Owing to these limitations, we were only able to compare our estimates with a limited number of studies. Nevertheless, we assume that GPs considered the most recent HbA_{1c} value, reported hypoglycaemic episodes, individual health status/preferences and side effects of medication when prescribing glucose-lowering medication.

The included variables in our models explained, as expected, only a small part of the total variation. Assessment of the effect of individual lifestyle modification, adherence to prescribed medication, GPs barriers to initiation, intensification or de-intensification of glucose-lowering medication using a longitudinal design would have increased the validity of the study. Our findings are probably most relevant for counties with similar healthcare systems.

4.2 | Implications

Our results may help GPs to identify individuals with type 2 diabetes who may benefit from less intensive or more intensive glucose-lowering treatment and those who need tighter follow-up with regular HbA_{1c} measurement. Longitudinal studies with the aims to develop strategies for improved management of hyperglycaemia in general practice are essential.

5 | CONCLUSION

We found lower rates of potential overtreatment in elderly individuals with type 2 diabetes compared with other studies. Our results also highlight the importance of timely initiation and intensification of glucose-lowering medication in men, non-westerners and those with low levels of education. De-intensification of glucose-lowering medication should be considered in elderly individuals with complex disease.

Performance of annual HbA_{1c} measurement in men and younger individuals could be improved.

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CONFLICT OF INTERESTS

J.G.C. has received lecturing fees from AstraZenica, Boehringer Ingelheim, Eli Lilly, Novo Nordisk, Sanofi Aventis, GSK and MSD. The other authors have no competing interests to declare.

AUTHORS' CONTRIBUTIONS

ATT conceptualized the present study, the application for linking the cross-sectional EHR data file with data from Statistics Norway, invited GPs and GP practices in Oslo/Akershus to participate the study, quality checked, performed the statistical analyses, drafted, reviewed and edited the manuscript. JGC, AKJ and TC conceived the study protocol, applied to the Regional Ethics Committee, invited GPs and GP practices, contributed to the discussion, and reviewed and edited the manuscript. BG, TJB, SS and TC conceived the study protocol and analysis plan, invited GPs and GP practices, contributed to the discussion, and reviewed and edited the manuscript. IM supervised the statistical analyses, reviewed and edited manuscript.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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