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ORIGINAL RESEARCH

The Economic Burden of Post-prandial Hyperglycemia (PPH) Among People with Type 1 and Type 2 Diabetes in Three Countries

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ABSTRACT

Introduction: Post-prandial hyperglycemia (PPH) among people with diabetes is a well-known clinical challenge to diabetes management. While the economic burden of diabetes is well studied, little is known about economic costs specific to PPH. The purpose of this study was to investigate costs of PPH related to work, diabetes management, and use of healthcare resources among people with diabetes taking bolus insulin.

Methods: Data were collected in a web survey of 906 adults with type 1 (39%) and type 2 (61%) diabetes taking bolus insulin in Germany (34%), the UK (26%), and the USA (40%).

Results: Sixty-two percent of respondents experienced PPH in the past week, and respondents averaged 1.7 episodes per week. Working respondents indicated that PPH affected their work productivity: 27% missed work time and 71% experienced work productivity issues while at work due to a recent episode of PPH. In terms of diabetes management, respondents with PPH in the past week measured their blood glucose (BG) more frequently than those without PPH (3.7 vs. 2.5 times/day, $P < 0.001$). PPH was also significantly associated with greater use of healthcare resources. Compared to those without PPH, respondents with PPH reported greater contact with healthcare professionals related to diabetes in the past year (5.5 vs. 4.4 visits, $P < 0.001$; 2.7 vs. 1.4 calls/emails, $P < 0.001$) and were more likely to report medical complications related to diabetes (72% vs. 55%, $P < 0.001$). Average annual costs associated with PPH due to missed work time, additional BG test strips, and physician visits were estimated to be $1239 USD per employed person in the USA.

Conclusion: Results indicate that PPH is associated with greater economic costs and that reducing the incidence of PPH would help

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mitigate such costs. Additional research is needed to better understand costs associated with PPH that may be more difficult to measure, as well as more long-term impacts and costs.
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Keywords: Diabetes management; Diabetes mellitus; Economic costs; Healthcare resources; Post-prandial hyperglycemia; Work productivity

INTRODUCTION

It is well established that better glycemic control among people with diabetes, as indicated by HbA1c values, is associated with a reduced risk of microvascular complications related to diabetes, and there is evidence that glycemic control reduces the risk of macrovascular complications in type 1 diabetes mellitus (T1DM) and in type 2 diabetes mellitus (T2DM) when control is achieved early in the course of the disease [1–4]. While research and diabetes management practices have long focused on HbA1c and fasting plasma glucose as indicators of glycemic control, more recent research highlights the importance of considering post-prandial blood glucose (PPG) as well for a more complete understanding of glycemic control [5]. There is now growing evidence that post-prandial hyperglycemia (PPH) may be particularly important for improving diabetes control, thereby reducing the risk of diabetes-related complications [2, 6]. Further, PPG control is particularly challenging for people with diabetes who take bolus insulin and must calculate and time their dose, which requires coordination with their daily scheduling, as well as remembering to take doses with them [7].

Recent research suggests that PPH has a negative impact on a number of health and daily functioning outcomes in people with diabetes [2]. There is evidence that PPH (or elevated post-challenge glucose following an oral glucose tolerance test) is associated with an increased incidence of cardiovascular disease (CVD) and cardiovascular events [8–12]. PPH is also associated with reduced cognitive functioning among aged people with T2DM [13]. Further, research suggests that PPH (or elevated post-challenge glucose) increases the risk of pancreatic cancer mortality, CVD mortality, and all-cause mortality [9, 14–18].

Given the negative health and functioning impacts associated with PPH among people with diabetes, there is also likely to be an economic burden related to PPH. While the economic cost of diabetes care and treatment is a well-known burden to healthcare budgets [19], little is known about the specific costs associated with PPH. The purpose of this study is to investigate the burden of PPH among people with T1DM and T2DM and related short-term costs associated with PPH in the areas of diabetes management, use of healthcare resources, and work.

METHODS

A web survey of people diagnosed with T1DM or T2DM and treated with self-administered basal plus bolus insulin was conducted in Germany, the UK, and the USA. Prior to commencement, the study received ethics approval from Copernicus Group IRB (# TBG1-11-116).

Survey Development

The process of survey development, including conducting focus groups and cognitive debriefing of the survey, followed Food and Drug Administration (FDA) guidelines for development of patient-reported outcomes (PROs) and accepted methodology for concept elicitation to ensure face validity and that items are comprehensive, relevant, and understandable to respondents [20]. As the survey collected data on the patient perspective, as per FDA guidelines, patients were considered the gold standard in generating item content. Nine semi-structured focus groups with a total of 77 people diagnosed with T1DM or T2DM and taking bolus insulin were conducted in Germany ($n = 20$), the UK ($n = 17$), and the USA ($n = 40$) to inform survey development. Transcript data from the focus groups were analyzed using adapted grounded theory [21], and thematic saturation occurred by the eighth focus group. Following survey development, survey items were assessed using cognitive debriefing with 12 individuals diagnosed with diabetes to ensure that survey instructions and items were clear, relevant, easy to understand, and inoffensive. Additionally, the cognitive debriefing was used to ensure that survey structure and recall periods were appropriate. Respondents were given the survey in the local language, and a professional translator was used to ensure consistency. The final survey was composed of 85 questions and took respondents approximately 30 min to complete. Respondents were given modest honoraria (approximately $15 USD per respondent) for completing the survey.

Participants

The web survey was administered to panels of respondents in Germany, the UK, and the USA between July and November of 2013. Inclusion/exclusion criteria required that participants be adults aged 18 years and older who were diagnosed with T1DM or T2DM by a physician or healthcare professional, and treated with bolus insulin therapy but not using pre-mixed insulin or glucagon-like peptide-1 analogs, with or without oral anti-diabetic drug (OAD) use, were eligible to complete the survey. Approximately, 7% of people approached for the survey were eligible to complete the survey based on the inclusion and exclusion criteria. Recruitment quotas were also used for country, age, work status, diabetes type, and method of insulin administration to achieve adequate sampling across various groups and to ensure a representative sample.

Survey Variables

All survey items were self-reported by respondents, and survey items included demographic and diabetes-related characteristics, experience of PPH, missed work time and reduced work productivity related to PPH, blood glucose (BG) measurement, and contact with physicians and other healthcare professionals. Subject characteristic survey measures included age, gender, ethnicity, marital status (percent married/partnered), level of education (percent with college degree), whether or not they work for pay, and the average number of hours worked per week. Diabetes and general health measures included age of diabetes diagnosis, age first took insulin, insulin method (needle/syringe, prefilled pen/durable pen, or insulin pump), how well diabetes controlled (percent indicating well/very well controlled as opposed to moderately/poorly/very poorly controlled), and general health status (percent indicating good/very good/excellent health as opposed to fair/poor health).

Experience of out-of-range PPG (BG after eating) was respondent-reported and based on the survey question, "In the last week (7 days), how many times did you have high/low blood sugar after eating?" PPG measures included whether respondent experienced PPH or post-prandial hypoglycemia in the past week, and the number of times respondent experienced PPH or post-prandial hypoglycemia in the past week. A 5% trim was conducted at the top levels to exclude possible reporting errors to calculate mean number of episodes. Respondents also reported on whether their most recent incident of out-of-range PPG was PPH or post-prandial hypoglycemia (or unsure), and the number of days since their most recent incident of out-of-range PPG (either PPH or post-prandial hypoglycemia).

Missed work time and reduced work productivity due to PPH were restricted to those whose most recent incident of out-of-range PPG was PPH (rather than post-prandial hypoglycemia or being unsure). Respondents indicated missed work time due to PPH (went into work late, left work early, missed a full day of work), and total missed work time (measured in minutes) due to PPG being out-of-range in the past week. The survey also measured presenteeism [22], defined as experience of reduced work productivity/functioning due to PPH (including missed/rescheduled meetings or appointments, making more mistakes, needing to take a break, difficulty focusing, and being less productive). Both missed work and presenteeism were respondent-reported as specifically due to PPH.

BG measurement variables included the number of times respondent measures BG on an average day, and in general, the number of additional times respondent measures BG when experiencing symptoms of hyperglycemia compared to a normal day. Healthcare resource utilization variables included the number of visits to a physician/healthcare professional related to diabetes in the past year, the number of calls/emails to physician/healthcare professional related to diabetes in the past year, and whether or not respondent has been diagnosed with any medical complications as a result of diabetes, including eye problems, nerve damage, cardiovascular problems and/or disease, kidney (renal) disease, high blood pressure, amputations, or other medical problems.

Costs associated with PPH were calculated based on missed work time, increased use of BG monitoring strips, and increased healthcare utilization. Estimates for the productivity costs of missed work time were calculated using respondent income. Employed respondents reported either hourly income or annual income. For those who indicated annual income, hourly income was computed by multiplying respondent-reported work hours per week times estimated work weeks per year for each country (Germany = 40, UK = 46, USA = 47, based on data from the Organisation for Economic Co-operation and Development [23] and the US Bureau of Labor Statistics [24]) to get an approximate total number of work hours per year and then dividing reported annual income by the estimated total number of work hours per year. Income was converted to USD based on exchange rates on July 22, 2013 (1 GBP = 1.5370 USD; 1 Euro = 1.3184 USD). A 5% trim at the top level was used for hourly income to exclude probable reporting errors. For respondents who did not wish to report income, average hourly income was used ($19.26 USD/h). Respondent missed work hours in past week was then multiplied by respondent hourly income to obtain an estimated cost of missed work time due to BG being out-of-range (either high or low BG) after eating in the past week. This estimate was then multiplied by the estimated average number of weeks worked per year for each country (Germany = 40, UK = 46, USA = 47) to get an approximate estimate of the productivity costs of missed work time associated with PPH per year.

To estimate the approximate cost of increased BG monitoring associated with PPH, the difference between those with and without PPH in the past week in the mean number of times respondents measure BG on an average day was calculated. This estimated additional BG tests associated with PPH per person per day was then multiplied by 365 (number of days in a year) to estimate an approximate number of additional BG tests associated with PPH per person annually. The estimated number of additional BG tests per person annually was then multiplied by the average cost of a BG test strip in each country to provide conservative estimates of the average annual costs of additional BG measurement due to PPH for each country. An average cost of 0.20 € ($0.26 USD) per BG test strip was used for Germany [25], $0.98 USD per BG test strip for the USA [26], and £0.24 GBP ($0.37 USD) per BG test strip for the UK [27], using the currency exchange rates noted above to calculate the USD equivalents.

The costs of additional physician/healthcare professional office visits significantly associated with PPH were estimated based on respondents' reported number of physician/healthcare professional office visits related to diabetes per year. The average number of additional annual office visits for those who experienced PPH compared to those without PPH was multiplied by the average cost of a physician/healthcare office visit for diabetes care in each country to estimate the annual costs of physician/healthcare office visits per year associated with PPH. Conservative estimates were used for physician/healthcare professional office visit costs. For the UK, an average cost of £105.00 ($161.39 USD, using currency exchange rate noted above) per visit was used, based on the average cost of non-consultant led outpatient diabetes care visits, which is less expensive than the average cost for consultant led outpatient visits [28]. For the USA, an average cost of $147.00 USD per visit was used for the USA, based on the average cost of outpatient physician office visits for general diabetes care (excluding visits for diabetes-related complications, which are generally more expensive, on average) [19]. Due to non-significant results, costs of additional physician visits associated with PPH were not estimated for Germany.

Data Analysis

All data were analyzed using SPSS Statistics Software, version 22 (IBM Corporation, Armonk, NY, USA). Analyses included descriptive statistics (means, standard deviations, ranges, and frequency percentages) and measures of association (comparison of means and cross-tabulations). Significance tests were also conducted. For comparison of means between two groups, *t* tests were used, and for comparison of means among three or more groups, analysis of variance was used [29]. The Chi-square test statistic was used to determine the significance of associations between categorical variables. All analyses were conducted by country and by diabetes type. Among people with T2DM, analyses revealed that results were generally similar whether or not respondents were taking OADs, so these results are not presented here. Comparisons were not possible for people with T1DM, as the vast majority were not taking OADs.

RESULTS

Sample Descriptive Statistics

A total of 906 respondents completed the survey [39% T1DM ($n = 356$); 61% T2DM ($n = 550$)]. As expected, respondents with T1DM were significantly younger on average compared to those with T2DM (37.4 vs. 47.4 years, respectively, $P < 0.001$; Table 1). Respondents with T1DM also had a significantly younger mean age of diagnosis compared to those with T2DM (20.2 vs. 35.6 years, $P < 0.001$), as well as a significantly younger average age first took insulin (20.9 vs. 39.6 years, $P < 0.001$). Respondents with T1DM were significantly more likely than those with T2DM to indicate being in "good," "very good," or "excellent" health (69.1% vs. 49.6%, $P < 0.001$). Respondents with T1DM were significantly more likely than those with T2DM to indicate that their diabetes was "well" or "very well" controlled (66.3% vs. 49.6%, $P < 0.001$). The full sample descriptive statistics by country are presented in Table 1.

Respondent Experiences of PPH

PPH was a frequent occurrence among respondents; 61.9% of respondents reported experiencing PPH in the past week, and 30.0% experienced three or more episodes of PPH in the past week (Table 2). On average, respondents experienced 1.7 episodes of PPH in that past week. In contrast, post-prandial hypoglycemia was relatively less frequent with 35.8% of respondents experiencing post-prandial hypoglycemia in the past week and 11.3% experiencing 3 or more episodes of post-prandial hypoglycemia. On average, respondents reported 0.6 episodes of post-prandial hypoglycemia in that past week. The average number of days since respondents' last incident of out-of-range post-prandial BG (either hyperglycemia or hypoglycemia) was 7.5 days, suggesting that many who have such events experience them frequently.

Respondents in the USA were significantly more likely to report experiencing PPH in the past week (66.6%) compared to those in Germany (63.0%) and the UK (53.4%, $P < 0.01$). Additionally, respondents in the USA reported a significantly greater average number of incidents of PPH in the past week (2.0), compared to respondents in the UK (1.5) and Germany (1.5, $P < 0.01$). Experience of PPH did not differ significantly by diabetes type.

PPH and Missed Work Time and Work Productivity Issues

Among working respondents whose most recent episode of out-of-range PPG was PPH (as opposed to post-prandial hypoglycemia or being unsure), 27.0% reported any missed work time due to that episode of PPH (Table 3). More specifically, 13.7% of respondents indicated that they went in late to work due to PPH, 18.6% indicated that they left early, and 9.9% reported missing a full day of work. On average, respondents reported a total of 168.2 min of missed work time in the past week due to BG being out-of-range after eating (either PPH or post-prandial hypoglycemia). There were no significant differences in reported missed work time by diabetes type or by country.

A majority of working respondents (70.7%) also reported that they experienced any kind of work productivity issues due to this last episode

Table 1 Descriptive statistics and diabetes/health characteristics by country

Characteristics		**Germany ($n = 305$)**	**UK ($n = 236$)**	**USA ($n = 365$)**	**Total ($n = 906$)**
Age	T1DM, mean(SD)***	32.0 (12.0)	40.1 (13.6)	41.0 (15.9)	37.4 (14.4)
	T2DM, mean(SD)***	43.7 (16.2)	44.5 (15.4)	51.2 (15.7)	47.4 (16.2)
Gender***	*n* (%) male	226 (74.1)	127 (53.8)	159 (43.6)	512 (56.5)
White/Caucasian***	*n* (%)	297 (97.4)	216 (91.5)	302 (82.7)	815 (90.0)
Marital status	*n* (%) married/partnered	184 (60.3)	148 (62.7)	202 (55.3)	534 (58.9)
Education***	*n* (%) college degree	81 (26.6)	132 (55.9)	146 (40.0)	359 (39.6)
Employed***	*n* (%) yes	202 (66.2)	155 (65.7)	162 (44.4)	519 (57.3)
Work hours per week**	Mean (SD)	37.0 (9.5)	32.6 (13.8)	35.4 (11.7)	35.2 (11.7)
Diabetes/health characteristics					
Age diagnosed	T1DM, mean (SD)	19.8 (11.3)	19.5 (11.7)	21.4 (13.2)	20.2 (12.1)
	T2DM, mean (SD)***	34.0 (13.8)	32.9 (13.9)	38.1 (13.8)	35.6 (14.0)
Diabetes type***	*n* (%) T1DM	130 (42.6)	117 (49.6)	109 (29.9)	356 (39.3)
	n (%) T2DM	175 (57.4)	119 (50.4)	256 (70.1)	550 (60.7)
Age 1st took insulin	T1DM, mean (SD)	20.4 (11.6)	20.2 (12.0)	22.3 (13.8)	20.9 (12.4)
	T2DM, mean (SD)***	36.6 (15.7)	36.5 (15.5)	43.1 (15.7)	39.6 (16.0)
Insulin method***	*n* (%) syringe	83 (27.2)	51 (21.6)	164 (44.9)	298 (32.9)
	n (%) prefilled pen	157 (51.5)	170 (72.0)	160 (43.8)	487 (53.8)
	n (%) insulin pump	65 (21.3)	15 (6.4)	41 (11.2)	121 (13.4)
How well diabetes controlled***	*n* (%) well/very well	216 (70.8)	127 (53.8)	166 (45.5)	509 (56.2)
Health status*	*n* (%) good/very good/ excellent	163 (53.4)	153 (64.8)	203 (55.6)	519 (57.3)
Diet and exercise habits					
Number of skipped meals in past week	Mean(SD)	1.5 (2.5)	1.3 (1.8)	1.2 (2.0)	1.4 (2.1)
Ate at restaurant in past week**	*n* (%) yes	154 (50.5)	109 (46.2)	214 (58.6)	477 (52.6)
Ate takeout in past week*	*n* (%) yes	100 (32.8)	78 (33.1)	152 (41.6)	330 (36.4)
Ate at friend's home in past week***	*n* (%) yes	170 (55.7)	82 (34.7)	135 (37.0)	387 (42.7)
Light physical activity past week**	Mean hours (SD)	8.3 (7.2)	6.5 (7.2)	6.6 (7.8)	7.2 (7.5)
Moderate physical activity past week**	Mean hours (SD)	4.3 (4.8)	2.8 (4.1)	3.2 (6.1)	3.5 (5.2)

Table 1 continued

Characteristics		Germany (*n* = 305)	UK (*n* = 236)	USA (*n* = 365)	Total (*n* = 906)
Hard physical activity past week**	Mean hours (SD)	2.0 (3.5)	1.5 (3.3)	1.1 (2.3)	1.5 (3.0)
Physical activity at work[a]	*n* (%) yes	40 (19.8)	33 (21.3)	35 (21.6)	108 (20.8)

Chi-square/analysis of variance tests indicate significant differences by country: * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$
SD standard deviation, *T1DM* type 1 diabetes mellitus, *T2DM* type 2 diabetes mellitus
[a] The question about physical activity at work was only asked of employed respondents

Table 2 Recent experience of PPH and post-prandial hypoglycemia by diabetes type

		T1DM (*n* = 356)	T2DM (*n* = 550)	Total (*n* = 906)
Experienced PPH in past week	*n* (%) yes	219 (61.5)	342 (62.2)	561 (61.9)
1 episode	*n* (%) yes	46 (12.9)	80 (14.5)	126 (13.9)
2 episodes	*n* (%) yes	70 (19.7)	93 (16.9)	163 (18.0)
3 or more episodes	*n* (%) yes	103 (28.9)	169 (30.7)	272 (30.0)
Number of times experienced PPH in past week[a]	Mean (SD)	1.6 (1.8)	1.8 (2.1)	1.7 (1.9)
Experienced post-prandial hypoglycemia in past week***	*n* (%) yes	153 (43.0)	171 (31.1)	324 (35.8)
1 episode	*n* (%) yes	58 (16.3)	83 (15.1)	141 (15.6)
2 episodes	*n* (%) yes	41 (11.5)	40 (7.3)	81 (8.9)
3 or more episodes	*n* (%) yes	54 (15.2)	48 (8.7)	102 (11.3)
Number of times experienced post-prandial hypoglycemia in past week[b,***]	Mean (SD)	0.8 (1.1)	0.5 (0.9)	0.6 (1.0)
Number of days since last incident of post-prandial blood glucose instability	Mean (SD)	8.1 (13.9)	7.1 (13.1)	7.5 (13.4)

Chi-square/*t* tests indicate significant differences by diabetes type: *** $P < 0.001$
PPH post-prandial hyperglycemia, *SD* standard deviation, *T1DM* type 1 diabetes mellitus, *T2DM* type 2 diabetes mellitus
[a] Data were trimmed by 5% at top level to exclude probable reporting errors ($n = 859$)
[b] Data were trimmed by 5% at top level to exclude probable reporting errors ($n = 867$)

of PPH. More specifically, 9.5% reported missing work meetings or appointments, 11.0% reported canceling and rescheduling a work meeting or appointment, 27.8% indicated that they made more mistakes at work, 43.7% needed to take a break at work, 54.4% found it difficult to focus, and 44.5% indicated being less productive at work due to PPH.

There were some significant differences in work productivity issues due to PPH by diabetes type and by country. Respondents with T2DM were significantly more likely to report having any work productivity issues due to PPH (77.0%) compared to those with T1DM (62.9%, $P < 0.05$). Additionally, respondents with T2DM were significantly

Table 3 Missed work time and work productivity issues due to post-prandial hyperglycemia among employed respondents by diabetes type

		T1DM ($n = 115$)	T2DM ($n = 148$)	Total ($n = 263$)
Any missed work time in past week	*n* (%) yes	26 (22.6)	45 (30.4)	71 (27.0)
Went in late to work	*n* (%) yes	13 (11.3)	23 (15.5)	36 (13.7)
Left work early	*n* (%) yes	18 (15.7)	31 (20.9)	49 (18.6)
Missed a full day of work	*n* (%) yes	12 (10.4)	14 (9.5)	26 (9.9)
Total missed work time in past week due to BG being out-of-range after eating (minutes)[a]	Mean (SD)	150.4 (186.9)	178.5 (181.3)	168.2 (182.6)
Any work productivity issues*	*n* (%) yes	72 (62.6)	114 (77.0)	186 (70.7)
Missed work meetings/appointments	*n* (%) yes	9 (7.8)	16 (10.8)	25 (9.5)
Canceled/rescheduled a meeting/appointment	*n* (%) yes	11 (9.6)	18 (12.2)	29 (11.0)
Made more mistakes at work	*n* (%) yes	25 (21.7)	48 (32.4)	73 (27.8)
Needed to take a break at work	*n* (%) yes	46 (40.0)	69 (46.6)	115 (43.7)
Found it difficult to focus**	*n* (%) yes	50 (43.5)	93 (62.8)	143 (54.4)
Was less productive at work*	*n* (%) yes	43 (37.4)	74 (50.0)	117 (44.5)

Chi-square/*t* tests indicate significant differences by diabetes type: * $P < 0.05$; ** $P < 0.01$
BG blood glucose, *SD* standard deviation, *T1DM* type 1 diabetes mellitus, *T2DM* type 2 diabetes mellitus
[a] Includes only those who reported missed work time in the past week ($n = 71$)

more likely to report that they found it difficult to focus due to PPH (62.8%) compared to those with T1DM (43.5%, $P < 0.01$). Respondents with T2DM were also significantly more likely to indicate that they were less productive at work due to PPH (50.0%) compared to those with T1DM (37.4%, $P < 0.05$). Respondents in Germany were significantly more likely to report any work productivity issues due to PPH (83.5%) compared to those in the USA (64.5%) and UK (61.6%, $P < 0.01$). Compared to respondents in the USA and UK, respondents in Germany were also significantly more likely to report that they made more mistakes at work (Germany, 37.1%; USA, 24.7%; UK, 19.2%, $P < 0.05$) and found it difficult to focus (Germany, 64.9%; USA, 46.2%; UK, 50.7%, $P < 0.05$) due to PPH.

The impact of PPH on missed work time and reduced work functioning/productivity is shown in Table 3.

PPH and BG Measurement

Respondents reported measuring BG 3.2 times on an average day and an average of 1.6 extra times compared to a normal day on days they experience symptoms of hyperglycemia. There were significant differences in frequency of BG measurement by whether or not respondent experienced PPH in the past week (Fig. 1). Respondents who experienced PPH in the past week reported measuring their BG a significantly greater number of times on an average day compared to respondents who did not experience PPH in the past week (3.7 vs. 2.5, $P < 0.001$). This is a difference of 1.2 tests

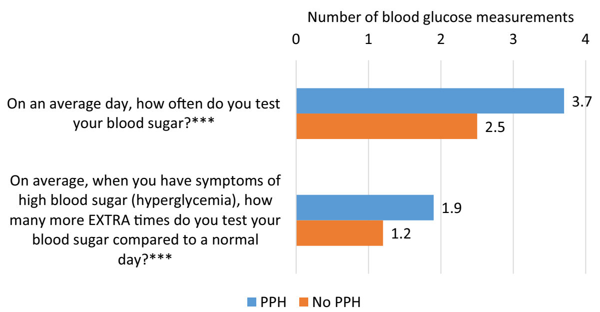

Fig. 1 Blood glucose measurement by experienced PPH in past week ($n = 906$). Note: t tests indicate significant differences by experience of PPH in past week (***$P < 0.001$). *PPH* post-prandial hyperglycemia

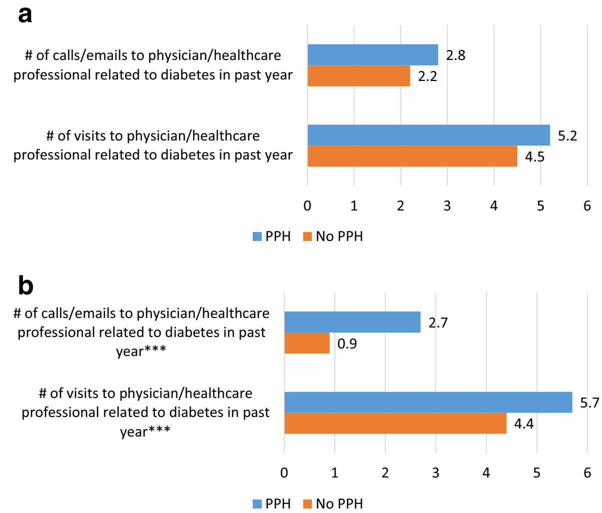

Fig. 2 Healthcare contact related to diabetes by experienced PPH in the past week among people with **a** type 1 diabetes ($n = 356$) and **b** type 2 diabetes ($n = 550$). Note: Chi-square tests indicate significant differences by experience of PPH (***$P < 0.001$). *PPH* post-prandial hyperglycemia

per day, which translates into approximately 438 additional BG tests per person per year associated with PPH. Further, respondents who experienced PPH in the past week also reported that they measure their BG a significantly greater number of extra times when they experience symptoms of hyperglycemia compared to those who did not experience PPH in previous week (1.9 vs. 1.2, $P < 0.001$). This suggests that those who experienced PPH measure their BG more frequently than those without PPH in the previous week both in general, on an average day, and when they experience symptoms of hyperglycemia. Results were similar by diabetes type and by country.

PPH and Healthcare Resource Utilization

Respondents who experienced PPH were significantly more likely to use healthcare resources than those without PPH. Specifically, those with PPH in the past week visited a physician or other healthcare professional 5.5 times for diabetes in the past year, compared to 4.4 times ($P < 0.001$) among those who did not experience PPH. Additionally, respondents who experienced PPH in the past week called or emailed a physician or other healthcare professional for diabetes a significantly greater number of times in the past year than those without PPH (2.7 vs. 1.4, $P < 0.001$). The impact of PPH on healthcare resource utilization by diabetes type is presented in Fig. 2.

As shown in Table 4, respondents who experienced PPH in the past week were also significantly more likely to report being diagnosed with one or more medical complications related to diabetes compared to those who did not experience PPH (71.7% vs. 54.5%, $P < 0.001$). The top three diabetes complications, all of which were significantly greater for those with PPH than those without, were high blood pressure (41.0% vs. 29.0%, $P < 0.001$), eye problems (33.3% vs. 21.2%, $P < 0.001$), and nerve damage/neuropathy (27.6% vs. 20.6%, $P < 0.05$).

There were some differences in results by diabetes type. The relationship between PPH

Table 4 Diagnosed medical complications related to diabetes by experienced post-prandial hyperglycemia (PPH) in past week and diabetes type

		T1DM ($n = 356$)		T2DM ($n = 550$)		Total ($n = 906$)	
		PPH ($n = 219$)	No PPH ($n = 137$)	PPH ($n = 342$)	No PPH ($n = 208$)	PPH ($n = 561$)	No PPH ($n = 345$)
Diagnosed with one or more medical complications related to diabetes	n (%) yes	131 (59.8)	62 (45.3)**	271 (79.2)	126 (60.6)***	402 (71.7)	188 (54.5)***
High blood pressure	n (%) yes	60 (27.4)	30 (21.9)	170 (49.7)	70 (33.7)***	230 (41.0)	100 (29.0)***
Eye problems	n (%) yes	84 (38.4)	27 (19.7)***	103 (30.1)	46 (22.1)*	187 (33.3)	73 (21.2)***
Nerve damage (neuropathy)	n (%) yes	44 (20.1)	21 (15.3)	111 (32.5)	50 (24.0)*	155 (27.6)	71 (20.6)*

Chi-square tests indicate significant differences by experience of PPH in past week: * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$
PPH post-prandial hyperglycemia, *T1DM* type 1 diabetes mellitus, *T2DM* type 2 diabetes mellitus

and contact with healthcare professionals was significant among respondents with T2DM, but not among those with T1DM. The associations between experience of PPH and reported nerve damage/neuropathy and between experience of PPH and reported high blood pressure were significant among respondents with T2DM, but not among respondents with T1DM.

Results also differed somewhat by country. The association between PPH and visits to doctors/healthcare professionals for diabetes in the past year was not significant among German respondents. Additionally, PPH and diagnosis of one or more medical complications due to diabetes were not significantly related among respondents in the USA. The link between PPH and eye problems was not significant among respondents in the UK. PPH and nerve damage/neuropathy were only significantly associated for respondents in the USA. Further, high blood pressure was not significantly different between those with and without PPH among respondents in the UK.

The Economic Costs of PPH

Costs of PPH included missed work time, extra use of BG monitoring strips, and healthcare resource utilization.

Average annual costs per person for missed work time were estimated among employed respondents using reported hourly income, missed work time in the past week, and average work weeks per year in each country. Costs were 394.78 € in Germany (given 8.48 € per week; 40 work weeks), £396.83 in the UK (given £8.62 per week; 46 work weeks), and $606.30 USD in the USA (given $13.05 USD per week; 47 work weeks). For comparison purposes, the equivalent costs for all countries in USD were $520.80 in Germany, $609.50 in the UK, and $606.30 in the USA. Estimated average cost of missed work in the past week did not differ significantly by diabetes type or country.

Annual costs of additional BG test strips associated with PPH were estimated to be 51.10 € in Germany (given 0.20 € per BG test

Table 5 Estimated annual costs associated with PPH by country and diabetes type

		Germany	UK	USA
Missed work time				
Estimated annual cost per employed person of missed work due to out-of-range PPG[a]	T1DM	$672.00	$763.14	$354.38
	T2DM	$565.20	$730.48	$474.23
BG measurement				
Estimated annual cost of additional BG measurement associated with PPH per person[b]	T1DM	$101.79	$254.00	$683.60
	T2DM	$38.28	$111.08	$382.06
Physician/HCP office visits related to diabetes				
Estimated annual cost of additional physician/HCP office visits associated with PPH per person[b,c]	T1DM	–	$188.82	$151.41
	T2DM	–	$451.88	$126.42
Total estimated costs	T1DM	$773.79	$1205.96	$1189.39
	T2DM	$603.48	$1293.44	$982.71

All costs reported in USD, using exchange rates from July 22, 2013

BG blood glucose, *HCP* healthcare professional, *PPG* post-prandial blood glucose, *PPH* post-prandial hyperglycemia, *T1DM* type 1 diabetes mellitus, *T2DM* type 2 diabetes mellitus

[a] Estimated using average number of work weeks in each country (Germany = 40, UK = 46, USA = 47)

[b] Estimates calculated using average local tariffs in each country, as reported in "Methods" section

[c] Costs not estimated for Germany due to non-significant association with PPH

strip [25] and an average of 0.7 additional BG tests per day), £113.88 GBP in the UK (given £0.24 GBP per BG test strip [27] and 1.3 additional BG tests per day), and $500.78 USD in the USA (given $0.98 USD per BG test strip [26] and 1.4 additional BG tests per day). For comparison purposes, the equivalent costs for all countries in USD were $67.37 in Germany, $175.03 in the UK, and $500.78 in the USA.

Annual costs of additional physician office visits related to PPH were £210.00 GBP in the UK (2.0 additional visits; £105 GBP per visit [28]; equivalent cost in USD was $322.77) and $132.30 in the USA (0.9 additional visits; $147 per visit [19]). As the association between PPH and physician office visits for diabetes care was not significant among German respondents, office visit costs due to PPH were not estimated for Germany.

Altogether, estimated costs associated with PPH may be substantial. Average annual costs of missed work time, additional BG test strips, and physician office visits associated with PPH in USD were $1107.30 in the UK and $1239.38 in the USA per employed person. In Germany, the average annual cost of missed work time and additional BG test strips associated with PPH was $588.17 USD per employed person.

Cost estimates by diabetes type and country are shown in Table 5.

DISCUSSION

Consistent with prior research [2], this study has shown that PPH is a frequent occurrence among people with T1DM and T2DM. While there is much discussion in the literature about the economic costs of diabetes in general, there is little understanding of specific costs associated with PPH among people with diabetes. The results from this study suggest that there may be substantial economic costs associated with PPH as a result of a broad range of impacts including missed work time, decreased worker productivity, increased BG measurement costs, and more frequent office visits to healthcare professionals and reported medical complications related to diabetes. In addition to these short-term impacts and economic costs, there are additional costs that are more difficult to quantify and assign a specific dollar value that should also be included in considering the economic burden of PPH. These include increased worker presenteeism, which is known to lead to decreased work productivity [22, 30], costs of additional calls and emails to healthcare professionals, which although not usually billable, do increase healthcare resource utilization, and costs due to increased rates of medical complications. The top three complications reported more frequently by those experiencing PPH were high blood pressure, eye problems, and nerve damage/ neuropathy.

In total, the estimated costs associated with PPH in this study may affect multiple groups as they are borne by patients, payers, the healthcare system, and employers. For example, increased costs of BG monitoring strips may be borne by either the patient as an out-of-pocket expense or by the payer, while increased physician or healthcare professional office visits are a cost to the healthcare system and payers. Thus, reducing costs associated with PPH would benefit society as a whole.

Results were generally similar for respondents with T1DM and T2DM, with some exceptions. Although the association between PPH and healthcare contact and between PPH and some medical complications did not reach statistical significance among those with T1DM, this may be due to the smaller sample size, or it may be that people with T1DM are more experienced in managing PPH due to their longer duration of diabetes and disease management, on average, compared to those with T2DM. Additionally, people with T2DM were significantly more likely than those with T1DM to report some work productivity issues due to PPH. It is possible that the severity of hyperglycemia might explain such differences, and this could be explored in future research. Some country differences were also evident, though explanations of such differences are beyond the scope of this study.

The study has several important limitations, which should be recognized. First, as with all surveys based on PROs, recall bias may have impacted results. The survey relied on patients to indicate their experiences with PPH and other outcomes, so it is possible that respondent recollections were inaccurate. Nevertheless, the survey used a recall period of 1 week for experience of PPH, which focus groups used to develop the survey indicated was appropriate. Selection bias may also have affected results. As with all studies relying on data from Internet surveys, respondents were drawn from panels of people who were required to be literate and have access to computers and the Internet. In the three countries studied, however, rates of literacy and internet use are both high. For instance, in the UK, the literacy rate is 99% [31], and approximately 83% of households had access to the internet in 2013 [32]. Additionally, given the cross-sectional, observational nature of the study, the results must be interpreted with caution. Causation may not be assumed in the associations found in the analyses. For instance, the association between PPH and healthcare contact among respondents does not necessarily mean that PPH causes more frequent doctor visits and calls/emails. There could be other unobserved factors associated with PPH that increase healthcare contact or additional BG measurement. Moreover, physician confirmation of respondent diabetes diagnosis and other clinical values was not possible due to the panel format of the internet survey. Thus, it is possible that some survey participants reported a diagnosis of diabetes when they had no such diagnosis in reality or reported their diabetes type inaccurately. It is unlikely, however, that such respondents were great enough in number to have an impact on the overall results. Potential respondents were not informed prior to the screener that only people with diabetes would be eligible to complete the survey. Clinical values, including BG measurements, were also not obtained. Such values would capture a more accurate measure of PPH, including the level of hyperglycemia, and may explain some differences in results by diabetes type. Last, further research is needed to explore other potential costs related to PPH and to estimate costs that are more difficult to measure. Future research could also explore how cross-country differences in factors such as diabetes care and treatment may affect the economic burden of PPH.

CONCLUSIONS

This is the first study to address an economic burden associated specifically with PPH among people with diabetes. The findings show that there are substantial costs associated with PPH, which should be included when calculating the cost of diabetes. These costs are the result of lost work productivity, increased diabetes management, and healthcare resource utilization. Reducing the incidence of PPH among people with diabetes would benefit not only patients but also payers, the healthcare system, and employers.

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Compliance with Ethics Guidelines. Prior to commencement, the study received ethics approval from Copernicus Group Institutional Review Board (# TBG1-11-116). All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1964, as revised in 2013. Informed consent was obtained from all participants for being included in the study.

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