

Modeling the Independent Effects of Gestational Diabetes Mellitus on Maternity Care and Costs

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OBJECTIVE—To explore the independent effects of gestational diabetes mellitus (GDM) on maternity care and costs.

RESEARCH DESIGN AND METHODS—Estimates for maternity care resource activity and costs for 4,372 women, of whom 354 (8.1%) were diagnosed with GDM, were generated from data from the Atlantic Diabetes in Pregnancy (ATLANTIC DIP) database. Multivariate regression analysis was applied to explore the effects of GDM on 1) mode of delivery, 2) neonatal unit admission, and 3) maternity care cost, while controlling for a range of other demographic and clinical variables.

RESULTS—Women with a diagnosis of GDM had significantly higher levels of emergency caesarean section (odds ratio [OR] 1.75 [95% CI 1.08–2.81]), their infants had significantly higher levels of neonatal unit admission (3.14 [2.27–4.34]), and costs of care were 34% greater (25–43) than in women without GDM. Other variables that significantly increased costs were weight, age, primiparity, and premature delivery.

CONCLUSIONS—GDM plays an independent role in explaining variations in rates of emergency caesarean section, neonatal unit admission, and costs of care, placing a substantial economic burden on maternity care services. Interventions that prevent the onset of GDM have the potential to yield substantial economic and clinical benefits.

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Gestational diabetes mellitus (GDM) is defined as any degree of glucose intolerance with onset or first recognition during pregnancy and is associated with several maternal and neonatal complications (1). Although a number of factors are associated with an increased risk of GDM, including older age, increased weight, personal history of GDM, family history of diabetes, and particular ethnic origins, robust evidence relating to the prevalence of GDM is lacking (2). Worldwide, reported prevalence rates of GDM have ranged from 1 to 14% (3). This is due to the range of different definitions and diagnostic test criteria that are used, as well as variations across regions and ethnic groups (4). Nonetheless, it is widely

accepted that GDM affects a significant number of pregnancies worldwide and that prevalence levels have been increasing rapidly in recent years (1). As a result, strategies to identify and treat GDM are being implemented in many countries, including Ireland, where O'Sullivan et al. (5) reported GDM prevalence levels of ~9% using the World Health Organization (WHO) criteria (6) and 12% using the new International Association of the Diabetes and Pregnancy Study Groups (IADPSG) criteria (7).

In terms of the economic issues of relevance to GDM, a new and growing field of research has emerged that has generally focused on exploring the costs of care associated with GDM as well as the cost-effectiveness of alternative GDM

screening strategies (8–15). Notably, however, such studies have presented results at an aggregate level, and no study to date has attempted to identify the independent effects of GDM on resource use and costs of care above the effects of other potentially important determinants. This is an important gap in the literature, because a clearer understanding of the role of GDM in determining resource use and costs can better inform the evaluation of prevention, screening, and treatment strategies for GDM in the future. Thus, within this context, this study uses data from the Atlantic Diabetes in Pregnancy (ATLANTIC DIP) (16) database to generate estimates of the independent effects of GDM on maternity care service use and costs, while controlling for a range of other demographic and clinical characteristics. This report contributes to the growing international literature in this area and also provides evidence that will be relevant to those charged with the design, planning, and evaluation of services for patients with GDM in Ireland and internationally.

RESEARCH DESIGN AND METHODS

Sample

ATLANTIC DIP is a network of five regional hospital centers along the Irish Atlantic seaboard serving a population of ~500,000 people. The hospitals serve rural and urban populations, including Galway City, the third largest city in the Republic of Ireland, implying the hospitals' patients can be considered as broadly representative of the whole population of Ireland. The network hosts a clinical information database that captures a comprehensive range of data on maternal characteristics, outcomes for mothers and infants, and health care resource usage over the course of pregnancy.

Pregnant women whose last menstrual period occurred between September 2006 and March 2009 were eligible to participate in ATLANTIC DIP. Ethical approval for the project was provided by the Health Service Executive Research Ethics Committee. With respect to GDM, the network

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provides universal screening for all pregnant women at 24–28 weeks' gestation using a 75-g oral glucose tolerance test (OGTT). The criteria for diagnosing GDM have, until recently, been based on WHO recommendations (6). During the course of the study, GDM was diagnosed according to WHO criteria, which classify overt diabetes as fasting and 2-h glucose ≥ 7.0 and ≥ 11.1 mmol/L, respectively, and impaired fasting glucose (IFG) and impaired glucose tolerance (IGT) as fasting and 2-h glucose of 6.1–6.9 and 7.8–11.0 mmol/L, respectively (6).

The sample for the current study consisted of 4,372 women who attended for testing during their pregnancy. The analysis excluded those who declined a screening offer or failed to attend for testing. A total of 354 (8.1%) of the study sample had a positive diagnosis for GDM, consisting of 102 (2.3%) with overt diabetes and 252 (5.8%) with IFG/IGT. All women with a positive result after testing were offered lifestyle intervention, blood glucose self-monitoring, and if required, insulin.

Outcomes

To model the independent effects of GDM on maternity care and costs, three separate dependent or outcome variables were considered in the multivariate statistical analysis: 1) mode of delivery; 2) neonatal unit admission; and 3) maternity care cost.

Mode of delivery was recorded in the Atlantic DIP database as a four-category variable: *a*) normal vaginal delivery, *b*) assisted vaginal delivery (including forceps and/or ventouse), *c*) elective caesarean section, and *d*) emergency caesarean section. Neonatal unit admission was recorded as a binary variable to denote whether an infant was admitted to the neonatal intensive care unit for any reason. Cost of maternity care was estimated by applying the appropriate unit cost-estimate to value resource activity for each participant. Unit costs, presented in Euros in 2009 prices, were estimated from the Health Service Executive Casemix database (17). The unit cost per mode of delivery was estimated as the weighted average of all diagnosis related group (DRG) categories per mode (weighted on the basis of the number of cases per DRG) in the database. Unit cost estimates of €2,417 per normal vaginal delivery, €3,599 per assisted vaginal delivery, €6,033 per elective caesarean section, and €7,518 per emergency caesarean

section were applied to value delivery care. A unit cost estimate of €7,528, the weighted average cost across all neonatal DRG admission categories in the Casemix database, was applied to value neonatal care.

Statistical analysis

A series of univariate and multivariate analyses were undertaken. The univariate analysis consisted of independent *t* tests for continuous variables and χ^2 tests for categorical variables. For the multivariate analyses, the choice of estimation approach was informed by the nature of the dependent variable under consideration in each model. In particular, multinomial logistic, binary logistic, and generalized linear model multivariate regression analysis was used to explore the effect of a range of independent variables on the three dependent variables of interest discussed above. In all cases, the main independent variable of interest was GDM diagnosis, whereas the identification strategy involved controlling for all possible differences between GDM and non-GDM patients. These independent variables included BMI, age, primiparity, family history of diabetes, previous miscarriage, ethnicity, and delivery week:

- BMI, calculated at the first obstetrical visit, was used to generate a three-category variable for the analysis: normal weight was classified as a BMI of less than 25 kg/m², overweight as between 25 and 30 kg/m², and obese as a BMI exceeding 30 kg/m².
- Age was included as a three-category variable, where patients were classified as being aged younger than 30 years, between 30 and 40 years, or being older than 40 years.
- Primiparous was recorded as a binary variable denoting whether the current pregnancy was the woman's first.
- Family history of diabetes was recorded as a binary variable, denoting the presence or otherwise of a diagnosis of diabetes in a first-degree family member.
- Previous miscarriage was recorded as a binary variable to indicate whether the women had experienced such an event.
- Ethnicity was recorded as a binary variable identifying the women as white/Caucasian or other.
- Delivery week was included in the models as a three-category variable to indicate whether the pregnancy reached term. The categories included were 39 weeks or longer (i.e., full term), between 36 and 39 weeks, or less than 36 weeks.

All of these variables were included as independent variables in each of the different models considered. Spearman correlation coefficients were estimated to examine the collinearity across these independent variables (Supplementary Table 1).

Furthermore, to test the robustness and sensitivity of our results and findings, we estimated a range of alternative model specifications. This included a secondary multivariate analysis that explored separately the independent effects of overt diabetes and IFG/IGT (see Supplementary Table 2), as specified using the WHO criteria (6), on the three dependent variables, as well as a set of univariate results for each independent variable.

In the multinomial logistic analysis for mode of delivery, the regression coefficients for each independent variable are presented as odds ratios (ORs) that estimate the likelihood of an assisted vaginal delivery, elective caesarean section, or emergency caesarean section relative to a normal vaginal delivery. In the binary logistic analysis for neonatal unit admission, the regression coefficients for each independent variable are reported in ORs that estimate the likelihood of neonatal admission. In the maternity cost analysis, a generalized linear model assuming a γ variance and a log-link was adopted for the analysis. This method has been shown to be appropriate for the analysis of the cost data, which is complicated in nature (18). For dichotomous variables in these models, the regression coefficient may be interpreted as the percentage change in cost relative to the reference group for that variable. For continuous variables, the coefficient may be interpreted as the percentage change in cost per unit change in that variable. Statistical significance was explored in two levels of α (0.01, 0.05), and model comparison was based on Akaike information criterion and log-likelihood statistics. All analyses were performed using STATA 11 software.

RESULTS—Data on clinical and demographic characteristics for study participants was identified from the ATLANTIC DIP database, and summary statistics for those with and without a diagnosis of GDM are provided in Table 1. Comparing GDM and non-GDM participants, it is notable that statistically significant differences exist with respect to age, ethnicity, parity, primiparity, BMI, family history of diabetes, previous miscarriage, and week of delivery. For example, in relation to BMI, the average (SD) index for GDM

participants was 30.8 (7), and was considerably higher than the average of 26.9 (5) for non-GDM participants. Indeed, this difference was statistically significant at a 1% level of significance. Given that factors such as BMI and the others listed in Table 1 may be potentially important determinants of resource use and costs, they are accounted for in the multivariate statistical analysis that follows.

Table 2 presents summary statistics for resource activities and costs for those with and without a diagnosis of GDM. In relation to the resource activities, GDM patients had lower rates of normal vaginal delivery (60.8 vs. 66.3%; $P = 0.0670$) and assisted vaginal delivery (13.2 vs. 18.2%; $P = 0.0430$) than non-GDM patients. However, for the most costly modes of delivery, GDM patients had higher rates of elective caesarean section (12.4 vs. 7.8%; $P = 0.0080$) and emergency caesarean section (13.6 vs. 7.7%; $P = 0.0010$), and these differences were statistically different from zero at the 1% level of significance. Neonatal unit admissions were also higher for GDM patients than non-GDM patients (28.7 vs. 10.1%; $P < 0.0001$) and again statistically different at the 1% level. The average (SD) cost for maternity care for non-GDM patients was €4,028 (€2,938), which was considerably lower than the €6,092 (€4,422) for GDM patients. This difference was statistically significant at the 1% level of significance. Thus, univariate analysis indicates that, overall, those with GDM in the sample had significantly higher rates of elective and emergency caesarean sections and neonatal admissions, as well as higher maternity care costs.

The results for the multivariate statistical analyses are presented in Table 3. Three separate models are presented, one each for mode of delivery, neonatal admission, and maternity cost. In relation to mode of delivery, the results indicate significant differences in mode of delivery for women depending on a range of factors, including GDM. In particular, GDM (OR 1.75 [95% CI 1.08–2.81], $P < 0.05$) was significantly associated with higher rates of emergency caesarean sections, even after accounting for a range of control variables. The model also suggests that women who were aged between 30 and 40 years and those aged older than 40 years and experiencing their first pregnancy were significantly more likely to have had an assisted vaginal delivery than a normal vaginal delivery. Conversely, women who delivered before

Table 1—Sample characteristics

Characteristics	Non-GDM $n = 4,018$	GDM $n = 354$	P^*
Age (years), mean (SD)	34.7 (5)	35.4 (6)	0.0125
White/Caucasian ethnicity, n (%)	3713 (93)	284 (81)	<0.0001
Parity, mean (SD)	0.97 (0.02)	1.24 (0.08)	0.0001
Primiparous, n (%)	1,764 (44)	130 (37)	0.011
BMI (kg/m^2), mean (SD)	26.9 (5)	30.8 (7)	<0.0001
Family history of diabetes, n (%)	1,345 (34)	202 (59)	<0.0001
Previous miscarriage, n (%)	913 (25)	105 (34)	<0.0001
Delivery week, mean (SD)	39.4 (2)	38.9 (2)	<0.0001

*Statistical analysis consisted of independent t tests for continuous variables and χ^2 tests for categorical variables.

36 weeks' gestation were significantly less likely to have had an assisted vaginal delivery. Women who were overweight, obese, aged older than 40 years, had a family history of diabetes, and who delivered at 36–39 weeks' gestation were significantly more likely to have had an elective caesarean delivery. Furthermore, the model suggests that women with GDM, who were overweight, obese, aged 30 to 40 years, aged older than 40 years, experiencing their first pregnancy, and who delivered before 36 weeks' gestation, were all significantly more likely to have had an emergency caesarean delivery compared with the base case.

Table 3 also presents results from the model of neonatal unit admissions. Again, the results indicate an independent effect of GDM (OR 3.14 [95% CI 2.27–4.34], $P < 0.01$) besides the other factors likely to influence this event. In addition to GDM, women who were obese, women who were experiencing their first pregnancy, women who delivered at 36–39 weeks' gestation, and those who were prior to 36 weeks' gestation were all significantly more likely to have had an admission.

The final model in Table 3 is that for maternity care costs. The results indicate that GDM was associated with significantly higher costs, with an estimated increase of 34% (95% CI 25–43%, $P < 0.01$) relative to those without a diagnosis of GDM. Other variables associated with significantly higher costs included obesity, age older than 30 years, first pregnancy, and delivery before term.

Overall, the results presented in Table 3 suggest that GDM is independently associated with higher rates of emergency caesarean section, neonatal admissions, and higher levels of maternity costs. The estimates presented are based on the preferred models, which were chosen on the basis of a number of statistical goodness-of-fit measures.

CONCLUSIONS—This study explored the determinants of maternity care and costs for 4,432 pregnant women in Ireland. In particular, we estimated the independent effects of GDM over and above the effects of other potentially important determinants, on mode of delivery, neonatal unit admission, and maternity

Table 2—Sample resource activity and costs

Variable	Non-GDM $n = 4018$	GDM $n = 354$	P^*
Resource activity			
Vaginal delivery, n (%)			
Normal	2294 (66.3)	161 (60.8)	0.067
Assisted	628 (18.2)	35 (13.2)	0.043
Caesarean section, n (%)			
Elective	271 (7.8)	33 (12.4)	0.008
Emergency	268 (7.7)	36 (13.6)	0.001
Neonatal unit admission, n (%)	395 (10.1)	98 (28.7)	<0.0001
Cost †			
Maternity care (€), mean (SD)	4,028 (2,938)	6,092 (4,422)	<0.0001

*Statistical analysis consisted of independent t tests for continuous variables and χ^2 tests for categorical variables. †Unit costs are presented in Euros in 2009 prices.

Table 3—Multivariate analysis results

Variable	Model 1: Mode of delivery, OR (SE)				Model 2: Neonatal admission OR (SE)	Model 3: Maternity cost Coefficient (SE)
	Vaginal delivery		Caesarean section			
	Normal (base category)	Assisted	Elective	Emergency		
GDM	—	1.15 (0.26)	1.18 (0.28)	1.75 (0.43)*	3.14 (0.52)**	0.34 (0.05)**
Weight						
Normal (base category)	—	—	—	—	—	—
Overweight	—	0.92 (0.10)	1.79 (0.31)**	1.53 (0.25)*	1.01 (0.14)	0.05 (0.03)
Obese	—	0.81 (0.12)	2.67 (0.48)**	2.56 (0.45)**	1.40 (0.20)*	0.21 (0.03)**
Age (years)						
<30 (base category)	—	—	—	—	—	—
30–40	—	1.62 (0.21)**	1.53 (0.36)	2.22 (0.45)**	1.00 (0.16)	0.10 (0.03)**
>40	—	1.81 (0.33)**	2.04 (0.54)**	2.79 (0.72)**	1.13 (0.23)	0.16 (0.04)**
Primiparous	—	7.75 (0.90)**	0.76 (0.13)	6.76 (1.05)**	1.50 (0.18)**	0.25 (0.03)**
Family history of diabetes	—	1.06 (0.11)	1.32 (0.18)*	0.96 (0.14)	1.17 (0.14)	0.03 (0.03)
Previous miscarriage	—	0.95 (0.12)	0.96 (0.14)	0.92 (0.16)	0.94 (0.13)	−0.03 (0.03)
Other ethnic group	—	0.84 (0.17)	0.63 (0.17)	1.30 (0.31)	0.70 (0.16)	−0.04 (0.04)
Delivery week						
≥39 weeks (base category)	—	—	—	—	—	—
36–39 weeks	—	0.80 (0.11)	3.40 (0.48)**	1.05 (0.19)	2.53 (0.31)**	0.24 (0.03)**
<36 weeks	—	0.39 (0.15)*	1.63 (0.68)	4.12 (1.05)**	46.60 (10.82)**	0.95 (0.07)**
Akaike information criterion	—	5,847.84			2,273.27	18.60
Log-likelihood	—	−2,887.92			−1,124.63	−30,451.83

Model 1—Multinomial logistic regression: ORs report the likelihood of each type of mode of delivery for each independent variable relative to the base category of normal vaginal delivery. Model 2—Logistic regression: ORs report the likelihood of neonatal admission relative to the base category for each independent variable. Model 3—Generalized linear model (γ variance and log-link function): Coefficients report the percentage difference in cost in Euros (€) relative to the base category. * $P < 0.05$. ** $P < 0.01$.

care costs. The need for such estimates is particularly relevant in the context of the continued growth in GDM prevalence rates worldwide and the resulting resource implications for already constrained health system budgets. A clearer understanding of the role of GDM in determining resource use and costs can better inform decisions regarding prevention, screening, and treatment strategies for GDM in the future. The multivariate analysis indicated that women with a diagnosis of GDM were 1.75-times more likely to require an emergency caesarean section and that their infants were 3.14-times more likely to be admitted to the neonatal intensive care unit. This translated into an overall increase of 34% in maternity care costs for women with GDM. Because these results were estimated while controlling for other individual level characteristics, we suggest that GDM plays an independent role in explaining variations in resource activity and costs of care. Notably, although the univariate analysis suggests otherwise, the multivariate analysis indicates that GDM did not influence the likelihood of requiring an assisted vaginal delivery or an elective caesarean

section. The robustness of these findings was generally supported by the results from the alternative model specifications.

Independent variables that were shown to significantly increase the likelihood of an assisted vaginal delivery included older age, primiparity, and delivery at full term. Variables that significantly increased the likelihood of an elective caesarean section were overweight, obesity, older age, a family history of diabetes, and premature delivery. Other variables that significantly increased the likelihood of an emergency caesarean section were overweight, obesity, older age, primiparity, and premature delivery. With respect to neonatal care, other variables that were shown to significantly increase the likelihood of an admission were obesity, primiparity, and premature delivery. Finally, other variables that were shown to significantly increase costs of care were obesity, increasing age, primiparity, and delivery week.

Our findings further and more clearly highlight the economic burden that GDM poses on maternity care services. Indeed, this burden is likely to rise in the future if current practices remain unchanged

given projected increases in GDM prevalence rates. However, the study also highlights the potential cost-savings that may arise from interventions that aim to prevent the onset of GDM in pregnancy. For example, an intervention that prevents the onset of GDM may be expected to reduce overall maternity care costs by 34%. Furthermore, in a supplementary analysis presented in the Supplementary Table 2, we estimated a model in which GDM diagnosis is divided into overt diabetes and IFG/IGT. The results indicated that overt diabetes was associated with an increase in cost of 26% (95% CI 8–44), and IFG/IGT was associated with an increase in cost of 36% (26–47%). Therefore, the design and implementation of interventions to prevent all forms of GDM have the potential to yield substantial economic and clinical benefits. Beyond the focus on GDM, it is also evident that strategies to reduce obesity levels in pregnancy have the potential to generate significant economic gains. Nonetheless, evidence of clinical and cost-effectiveness would be required before such interventions could be introduced in clinical practice.

This study has a number of limitations. Firstly, because the uptake of screening was 44%, we were unable to model the resource use and costs for women with undetected and untreated GDM. Those who refused or did not attend for an OGTT after initially consenting were statistically slightly younger and of a lower BMI, but there was no difference in ethnicity. It is possible, therefore, that the actual prevalence within the population as a whole may be slightly lower than identified in our study. However, it is important to note that complete data were not available for all of the women who did not participate and that the absolute differences seen were relatively small. We believe on the basis of these findings that the study sample is representative of the population at large in the region.

Secondly, data on other potentially important drivers of resource use and cost were not collected in the database. For example, private health insurance status, which is related to earnings and socioeconomic status, has been shown to influence the utilization of health care services in Ireland (19). Individuals may voluntarily purchase private health insurance that provides access to private care services that are not available to public patients. In the case of maternity care, those with access to insurance may have higher levels of elective caesarean section; however, we were unable to distinguish between those with and without insurance in the current analysis.

In addition, resource data at the individual level for specific GDM treatment, including lifestyle intervention, blood glucose monitoring, and insulin, were not collected in the database. Therefore, we were unable to cost these items and to explore the outcomes for women with GDM who required insulin compared with those who did not. However, we did attempt to explore the issue of disease severity by separating GDM diagnosis into overt diabetes and IFG/IGT (see Supplementary Data). This notwithstanding, future studies should attempt to include these and other potentially important independent variables.

Thirdly, while the cross-sectional nature of the data precludes us from making definitive conclusions regarding causality, the sporadic nature of pregnancy has limited our ability to build a panel dataset of pregnancies for the study cohort. Other approaches, such as statistical matching methods, were not considered in the current analysis given the desire to explore the determinants of care and costs

across the full patient population. In addition, there are some concerns regarding the collinearity between variables such as GDM, BMI, ethnicity, and family history of diabetes (see Supplementary Data) that may explain the lack of significance for the effects of GDM coefficients on emergency caesarean section in multivariate model. Nonetheless, we concluded it was necessary to include as comprehensive a list of independent variables as possible to ensure a robust analysis of the independent effects of GDM on the outcomes of interest. Moreover, model comparison statistics indicated that the reported model performed at least as well as the alternative parsimonious model specifications.

Finally, although we explicitly focus on maternity care costs, this constitutes an underestimation of the overall cost of GDM, which also includes the costs of GDM screening, treatment, antenatal care, care after hospital discharge, private out-of-pocket expenses, and additional losses to the broader society. Maternity care is likely to be a significant individual contributor to the overall cost of care, but future studies should attempt to include a broader cost perspective. Furthermore, the process of conducting cost analysis in Ireland is complicated by the lack of nationally available unit cost data. In this case, we estimated average unit costs based on DRG category costings from the national hospital database.

This study provides estimates of the independent effects of GDM on maternity care service use and costs. The analysis provides information that will be useful to future research that seeks to examine questions of costs and cost effectiveness in relation to GDM prevention, screening or treatment. Furthermore, the study contributes to the international literature in this area by providing data on these as they arise in an Irish setting.

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P.G., J.C., and C.O. conceived the study, analyzed the data, wrote the initial manuscript, participated in critical revision of the manuscript, and saw and approved the final version. F.D. conceived the study, acquired data from the ATLANTIC DIP database, wrote the initial manuscript, participated in critical revision of the manuscript, and saw and approved the final version. P.G. is the guarantor of this work and,

as such, had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

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