The final version of this paper was published in the *Australian and New Zealand Journal of Obstetrics and Gynaecology* 2015; 55:350-356

Variation in hospital caesarean section rates for preterm births

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Background: Evidence about optimal mode of delivery for preterm birth is lacking and there is thought to be considerable variation in practice.

Objective: To assess whether variation in hospital preterm caesarean section rates (Robson Classification Group 10) and outcomes are explained by casemix, labour or hospital characteristics.

Materials and Methods: Population-based cohort study in NSW, 2007-2011. Births were categorised according to degree of prematurity and hospital service capability: 26-31 weeks, 32-33 weeks and 34-36 weeks. Hospital preterm caesarean rates were investigated using multilevel logistic regression models, progressively adjusting for casemix, labour and hospital factors. The association between hospital caesarean rates, and severe maternal and neonatal morbidity rates was assessed.

Results: At 26-31 weeks the caesarean rate was 55.2% (7 hospitals, range 43.4-58.4%); 50.9% at 32-33 weeks (12 hospitals, 43.4- 58.1%); and 36.4% at 34-36 weeks (51 hospitals, 17.4-48.3%). At 26-31 weeks and 32-33 weeks, 81% and 59% of the variation between hospitals was explained with no hospital significantly different from the state average after adjustment. At 34-36 weeks, although 59% of the variation was explained, substantial unexplained variation persisted. Hospital caesarean rates were not associated with severe maternal morbidity rates at any gestational age. At 26-31 weeks medium and high caesarean rates were associated with higher severe neonatal morbidity rates, but there was no evidence of this association ≥32 weeks.

Conclusion: Both casemix and practice differences contributed to the variation in hospital caesarean rates. Low preterm caesarean rates were not associated with worse outcomes.

Keywords: preterm birth, caesarean section, maternal outcome, neonatal outcome, record linkage

Introduction

Preterm births are a major cause of neonatal morbidity and mortality[1] and there is uncertainty about the optimal mode of delivery at preterm gestation.[2] Studies suggest that caesarean section is associated with improved neonatal outcomes for subgroups of mothers or infants with major co-morbidities.[3-5] However, there is no difference in outcomes compared to vaginal delivery for most singleton cephalic preterm infants, suggesting that prematurity alone is not an indication for caesarean section.[3-5]

Consistent with the lack of clear evidence about optimal mode of delivery, there is considerable variation in caesarean rates among preterm births.[6, 7] Variation in preterm caesarean rates may reflect differences in the demographic characteristics and health status of the source population ('casemix') as well as differences in clinical practice and hospital characteristics. Previous studies that have explored variation in preterm caesarean section rates have been limited by the lack of comprehensive data on maternal co-morbidities, pregnancy history[6, 7] and hospital characteristics.[7] There is limited evidence on the maternal and neonatal outcomes associated with variation in preterm caesarean rates.[7]

The aims of this study were to describe variation in hospital preterm caesarean rates, determine whether variation is explained by casemix, labour management or hospital

characteristics and determine whether variation in preterm caesarean section rates is associated with adverse maternal and neonatal outcomes.

Methods

This population-based cohort study included all women who delivered a singleton cephalic-presenting infant (Robson Classification Group 10) in hospitals in New South Wales (NSW), Australia, between 2007 and 2011.[8]

Births were categorised according to degree of prematurity and analyses were limited to hospitals with the necessary service capability for each category: 26-31 weeks (7 hospitals), 32-33 weeks (12 hospitals) and 34-36 weeks (51 hospitals).[9] Preterm births at lower-level hospitals are rare and reflect emergency unplanned deliveries and were excluded from the study (Supplementary Figure S1). Births earlier than 26 weeks gestation were excluded as considerations about viability at earlier gestations are likely to affect decisions about mode of delivery.

Data were obtained from two linked population-based data collections: the NSW Perinatal Data Collection (referred to as birth data), a legislated surveillance system of all live births and stillbirths of at least 20 weeks gestation or 400g birthweight in NSW, and the Admitted Patients Data Collection (referred to as hospital data), a census of all discharges from NSW hospitals. The birth data includes maternal and infant demographic,

medical and obstetric information for pregnancy, labour and delivery. The hospital data includes diagnoses coded using the International Classification of Diseases and Related Health Problems, Tenth Revision, Australian Modification (ICD10-AM) and procedures coded using the Australian Classification of Health Interventions (ACHI). Probabilistic record linkage of the birth and hospital data was conducted by the NSW Centre for Health Record Linkage. The data sets and data linkage have been validated for use in research.[10-15] The NSW Population and Health Services Research Ethics Committee approved the study (#2012/12/430). Anonymised data was provided to the researchers.

The primary outcome was the hospital preterm caesarean section rate. Risk factors for caesarean delivery were grouped as casemix factors and labour interventions, and hospital characteristics and are listed in Tables 1 and 2 respectively. The secondary outcomes were severe maternal and neonatal morbidity. Severe morbidity was measured using validated composite outcome indicators that include both life-threatening conditions (e.g. respiratory failure, cerebrovascular haemorrhage, shock and cardiac arrest) and procedures associated with severe morbidity (e.g. mechanical ventilation, blood transfusion, acute dialysis and surgical procedures).[16, 17] In order to explore the association between variation in caesarean section rates and severe neonatal morbidity at 26-31 weeks gestation, we modified the neonatal severe morbidity indicator such that births before 32 weeks or at less than 1500g were not automatically coded as having severe morbidity.[17].

Statistical analysis

We used a multilevel modeling approach to explore variation in hospital preterm caesarean rates while taking clustering of births with similar characteristics at each hospital into account. A multilevel logistic regression model with a random intercept for each hospital was used to model the odds of caesarean section for a woman nested within a hospital. Models were fitted using a four-stage approach as described in detail by Nippita et al.[18] First, a null model with hospital random intercepts only was fit to calculate the crude hospital-level variation in caesarean section rates. Models were then run to sequentially adjust for casemix, labour interventions and hospital characteristics to determine the amount of variation explained by each stage of adjustment.

At each stage of model adjustment, the hospital specific odds of caesarean section were converted into a hospital caesarean rate and plotted in rank order from lowest to highest unadjusted caesarean section rate with 95% confidence intervals. We calculated the relative contribution of each stage of adjustment to explaining the variation in the null model by subtracting the variance of the random effect in the preceding model from the variance of the random effect in the current model, expressed as a percentage of the variance of the random effect in the null model.[18]

To describe the association between variation in preterm caesarean rates and severe maternal and neonatal morbidity, we used multilevel logistic regression models to

calculate hospital severe maternal and neonatal morbidity rates adjusted for casemix, using the same approach as described for modeling caesarean section rates. We produced scatter plots of the association between hospital caesarean section rates adjusted for casemix, labour and hospital characteristics, and severe morbidity rates adjusted for casemix. Finally, we modeled the association between hospital caesarean rates and individual-level odds of severe maternal morbidity and severe neonatal morbidity. Hospital caesarean section rates were grouped as tertiles (<34 weeks) and quintiles (34-36 weeks) as the primary exposure for severe morbidity. Casemix factors were included as potential confounders of the association between hospital caesarean rates and severe maternal or neonatal morbidity.

Results

The study population comprised 20,247 preterm births, including 1905 born at 26-31 weeks, 2,010 born at 32-33 weeks and 16,332 born at 34-36 weeks gestation. The casemix and labour management characteristics of the study population are described in Table 1 and the hospital descriptors in Table 2.

At 26-31 weeks gestation, 1,042 (55%) women were delivered by caesarean section, comprising 133 (13%) caesarean sections after spontaneous labour onset, 42 (4%) caesarean sections after induction of labour and 867 (83%) pre-labour caesarean sections. At 32-33 weeks gestation, 1,020 (51%) women were delivered by caesarean section,

comprising 129 (13%) caesarean sections after spontaneous labour onset, 60 (6%) caesarean sections after induction of labour and 831 (81%) pre-labour caesarean sections. At 34-36 weeks gestation, 5,897 (36%) women were delivered by caesarean section, including 1,476 (25%) caesarean sections after spontaneous labour onset, 704 (12%) caesarean sections after induction of labour and 3,717 (63%) pre-labour caesarean sections.

Variation in hospital preterm caesarean section rates

Among births at 26-31 weeks gestation, the unadjusted hospital caesarean section rate ranged from 43.4% to 58.4% (p=0.001). Adjusting for casemix explained 33% of the variation and there was limited evidence for variation in hospital caesarean section rates (p=0.07). There was no evidence of variation after adjusting for labour interventions and hospital characteristics (adjusted rates varied from 51.4% to 55.4%, p=0.32) (Supplementary Figure S2A-D and Table S1). Overall, 81.0% of variation in caesarean section rates at 26-31 weeks gestation was explained.

Among births at 32-33 weeks gestation, the unadjusted caesarean rate ranged from 43.1% to 58.2% (p<0.0001). Adjusting for casemix increased variation by 49.7%. Adjusting for labour interventions explained 59.9% of the variation and adjusting for hospital characteristics explained a further 49.2% of the variation, at which point there was no evidence of unexplained variation in caesarean section rates (adjusted rates varied from

45.4% to 52.8%, p=0.14) (Supplementary Figure 3A-D and Table S2). Overall 59.3% of variation in caesarean section rates was explained.

Among births at 34-36 weeks gestation, the unadjusted caesarean rate ranged from 17.4% to 48.3% (p<0.0001). Adjusting for casemix explained 50.7% of the variation, with the exception of prelabour rupture of membranes (PPROM) which increased variation by 7.6%. Additionally, adjusting for labour interventions increased variation by 5.9%. Adjusting for hospital characteristics explained 21.2% of variation. Overall 58.6% of variation in caesarean section rates was explained by casemix, labour and hospital characteristics but there was still strong evidence of unexplained variation in caesarean section rates (adjusted caesarean section rates ranged from 27.5% to 45.4%, p<0.0001) (Figure 1A-D, Supplementary Table S4).

Association between variation in caesarean section rates and severe morbidity

The crude incidence of severe *maternal morbidity* was 8% at 26-31 weeks, 7% at 32-33 weeks and 4% at 34-36 weeks gestation. The casemix-adjusted incidence of severe maternal morbidity varied between hospitals from 6% to 9% at 26-31 weeks, 5% to 9% at 32-33 weeks and 3% to 4% at 34-36 weeks gestation. There was no evidence for an association between caesarean section rates and severe maternal morbidity at any gestational age (Table 3, Supplementary Figures S4-S6A).

The crude incidence of severe *neonatal morbidity* was 89% at 26-31 weeks, 63% at 32-33 weeks and 19% at 34-36 weeks gestation. The casemix-adjusted incidence of severe neonatal morbidity varied between hospitals from 86% to 90% at 26-31 weeks, 51% to 71% at 32-23 weeks and 10% to 34% at 34-36 weeks gestation. Medium and high caesarean section rates were associated with increased odds of severe neonatal morbidity at 26-31 weeks gestation (Table 3, Figure 5B) but there is no evidence that higher caesarean section rates were associated with severe neonatal morbidity at 32-33 weeks or 34-36 weeks gestation (Table 3, Supplementary Figure S4-S6B).

Discussion

We found that variation in hospital rates of caesarean section for preterm birth was particularly pronounced for births at 34-36 weeks gestation with adjusted rates varying from 27% to 45%. In contrast, at gestations <34 weeks adjusted caesarean rates ranged from 45% to 55% with no hospital significantly different from the state average after adjustment. The latter is reassuring as it suggests that women presenting or transferring to tertiary hospitals with maternal or fetal complications resulting in extreme, severe or moderate preterm birth are receiving broadly consistent obstetric management with respect to mode of delivery.

At 34-36 weeks gestation variation persisted after adjusting for casemix, labour interventions and hospital factors, although the number of hospitals significantly different from the state average declined from 24 (of 51) to 7 after adjustment (Figure 1A-D). At both 32-33 weeks and 34-36 weeks gestation, PPROM, placental morbidity, hypertension and previous caesarean section were particularly influential casemix factors and women with these factors may be experiencing different obstetric management at different hospitals. At 34-36 weeks PPROM and labour interventions actually increased variation. This may reflect uncertainty about the management of PPROM at these gestations.[19] However, recent randomised trial results support a policy of expectant management of PPROM at 34-36 weeks.[20] Uptake of the trial evidence may lead to a reduction in preterm caesarean rates at these gestations. As the majority of preterm births occur at 34-36 weeks gestation, variation in hospital caesarean section rates at these gestations potentially represents a substantial cost to the healthcare system in terms of the quality, equity and efficiency of health care provision.[21]

We found no evidence that relatively high caesarean section rates are associated with improved maternal or neonatal outcomes. In contrast, at 26-31 weeks gestation we found evidence that relatively high caesarean section rates are associated with poorer neonatal outcomes. Previous studies have also found that caesarean section is associated with adverse neonatal outcomes for singleton cephalic infants at preterm gestations.[3, 22, 23] However, our findings may also reflect confounding by indication as infants delivered by

caesarean section may have been at increased risk of adverse outcomes regardless of mode of delivery. Given that caesarean section is an important risk factor for maternal morbidity in future pregnancies and that caesarean section may be associated with adverse neonatal outcomes,[24, 25] it would be instructive to investigate practices at hospitals with relatively low preterm caesarean section rates to determine whether preterm caesarean section rates can be safely reduced.

The strengths of our study include the use of linked population-based data for a large, contemporary maternity population that represents a third of all births in Australia.[13] The variables and data sources in this study have been validated for use in research in several studies.[10-12, 14-17, 26] We have improved on previous studies of variation in preterm caesarean section rates[6, 7] by including comprehensive data on maternal co-morbidities and history of adverse birth outcomes and by adjusting for clustering of women with similar characteristics at different hospitals. We have also improved on previous work by investigating whether variation in caesarean section rates is associated with individual-level and hospital-level severe maternal or neonatal morbidity, which is important for determining whether observed variation is 'unwarranted' in terms of health outcomes.[21, 27] Many previous studies of mode of delivery for preterm births considered all births before 37 weeks together,[6] or restricted to severe prematurity.[7] By analysing preterm births in three gestational age groups, we were able to investigate variation in caesarean section rates in clinically similar groups and demonstrate that most variation in caesarean

section occurs in the late preterm group at 34-36 weeks gestation, when most preterm births occur.

Although we included data on a range of potential confounders, some variation may be explained by residual confounding caused by unmeasured risk factors. Our modelling strategy comprised sequential stages of adjustment for individual-level then hospital-level characteristics. One limitation of this approach is that variation that is strongly related to hospital characteristics, such as hospital induction rate, are mostly attributed to individual-level factors associated with these hospital characteristics, such as patient-level private obstetric care. A further limitation is that our analysis was concerned with variation in caesarean section rates given that birth occurred at a particular gestation. However there is also variation in gestational age at which deliveries occur, due to differences in hospital practice around immediate delivery compared to expectant management.[28]

Conclusion

There is substantial variation in hospital caesarean section rates for preterm births at 34 to 36 weeks gestation that cannot be explained by casemix, labour or hospital characteristics. As most preterm births occur at 34 to 36 weeks gestation, how variation in hospital caesarean section rates at 34 to 36 weeks gestation can be reduced needs to be investigated, which requires better evidence on the optimal mode of delivery for these

infants. High caesarean section rates are not associated with improved maternal or neonatal outcomes, suggesting that it may be possible to safely reduce caesarean section rates for preterm births.

Acknowledgements

We thank the NSW Ministry of Health for access to the population health data and the NSW Centre for Health Record Linkage for linking the data sets. This work was supported by an Australian National Health and Medical Research Council (NHMRC) Capacity Building (573122) and Centre for Research Excellence Grants (1001066). Christine Roberts is supported by a NHMRC Senior Research Fellowship (#APP1021025). Jane Ford is supported by an Australian Research Council Future Fellowship (#FT120100069).

References

1. Goldenberg RL, Culhane JF, Iams JD, Romero R. Epidemiology and causes of preterm birth. *Lancet* 2008; **371**(9606): 75-84.

2. Alfirevic Z, Milan Stephen J, Livio S. Caesarean section versus vaginal delivery for preterm birth in singletons. *The Cochrane database of systematic reviews*, 2013. http://onlinelibrary.wiley.com/doi/10.1002/14651858.CD000078.pub3/abstract (accessed.

3. Werner EF, Savitz DA, Janevic TM, et al. Mode of delivery and neonatal outcomes in preterm, small-for-gestational-age newborns. *Obstetrics and gynecology* 2012; **120**(3): 560-4.

4. Lee HC, Gould JB. Survival Rates and Mode of Delivery for Vertex Preterm Neonates According to Small- or Appropriate-for-Gestational-Age Status. *Pediatrics* 2006; **118**(6): e1836-e44.

5. Högberg U, Holmgren PA. Infant mortality of very preterm infants by mode of delivery, institutional policies and maternal diagnosis. *Acta Obstet Gynecol Scand* 2007; **86**(6): 693-700.

6. Lee YY, Roberts CL, Patterson JA. Unexplained variation in hospital caesarean section rates. *The Medical journal of Australia* 2014; **200**(2): 84-5.

7. Zeitlin J, Di Lallo D, Blondel B, et al. Variability in caesarean section rates for very preterm births at 28–31 weeks of gestation in 10 European regions: Results of the MOSAIC project. *Eur J Obstet Gyn R B* 2010; **149**(2): 147-52.

8. Robson M. Classification of caesarean sections. *Fetal Matern Med Rev* 2001; **12**(01): 23-39.

9. NSW Department of Health. Guide to the role delineation of health services www.health.nsw.gov.au/services/Pages/guide-role-delineation-health-services.aspx (Accessed Nov 2014). 3rd ed; 2002.

10. Bell JC, Ford JB, Cameron CA, Roberts CL. The accuracy of population health data for monitoring trends and outcomes among women with diabetes in pregnancy. *Diabetes Res Clin Pr* 2008; **81**(1): 105-9.

11. Roberts CL, Ford JB, Lain S, Algert CS, Sparks CJ. The accuracy of reporting of general anaesthesia for childbirth: a validation study. *Anaesthesia and intensive care* 2008; **36**(3): 418-24.

12. Roberts CL, Bell JC, Ford JB, Hadfield RM, Algert CS, Morris JM. The Accuracy of Reporting of the Hypertensive Disorders of Pregnancy in Population Health Data. *Hypertens Pregnancy* 2008; **27**(3): 285-97.

13. Bentley J, Ford J, Taylor L, Irvine K, Roberts C. Investigating linkage rates among probabilistically linked birth and hospitalization records. *BMC Med Res Methodol* 2012; **12**(1): 149.

14. Roberts CL, Bell JC, Ford JB, Morris JM. Monitoring the quality of maternity care: how well are labour and delivery events reported in population health data? *Paediatr Perinat Epidemiol* 2009; **23**(2): 144-52.

15. Hadfield RM, Lain SJ, Cameron CA, Bell JC, Morris JM, Roberts CL. The prevalence of maternal medical conditions during pregnancy and a validation of their reporting in hospital discharge data. *Aust N Z J Obstet Gynaecol* 2008; **48**(1): 78-82.

16. Roberts CL, Cameron CA, Bell JC, Algert CS, Morris JM. Measuring Maternal Morbidity in Routinely Collected Health Data: Development and Validation of a Maternal Morbidity Outcome Indicator. *Med Care* 2008; **46**(8): 786-94 10.1097/MLR.0b013e318178eae4.

17. Lain SJ, Algert CS, Nassar N, Bowen JR, Roberts CL. Incidence of severe adverse neonatal outcomes: use of a composite indicator in a population cohort. *Matern Child Health J* 2012; **16**(3): 600-8.

18. Nippita TA, Lee YY, Patterson JA, et al. Variation in hospital caesarean rates and obstetric outcomes among nulliparae at term: a population based cohort study. *BJOG* 2014; **(in press)**.

19. Buchanan S, Crowther C, Morris J. Preterm prelabour rupture of the membranes: A survey of current practice. *Aust N Z J Obstet Gynaecol* 2004; **44**(5): 400-3.

20. Morris JM, Algert C, Crowther C, Bond D, Bowen J, C.L. R. Preterm prelabour rupture of the membranes close to term (PPROMT) trial. *J Paediatr Child H* 2014; **50**(S1): 23-4.

21. Corallo AN, Croxford R, Goodman DC, Bryan EL, Srivastava D, Stukel TA. A systematic review of medical practice variation in OECD countries. *Health Policy* 2014; **114**(1): 5-14.

22. Werner EF, Han CS, Savitz DA, Goldshore M, Lipkind HS. Health Outcomes for Vaginal Compared With Cesarean Delivery of Appropriately Grown Preterm Neonates. *Obstetrics and gynecology* 2013; **121**(6): 1195-200 10.097/AOG.0b013e3182918a7e.

23. Muhuri P, MacDorman M, Menacker F. Method of Delivery and Neonatal Mortality among Very Low Birth Weight Infants in the United States. *Matern Child Health J* 2006; **10**(1): 47-53.

24. Morris JM, Algert CS, Falster MO, et al. Trends in planned early birth: a population-based study. *Am J Obstet Gynecol* 2012; **207**(3): 186 e1-8.

25. Spong CY, Berghella V, Wenstrom KD, Mercer BM, Saade GR. Preventing the first cesarean delivery: summary of a joint Eunice Kennedy Shriver National Institute of Child Health and Human Development, Society for Maternal-Fetal Medicine, and American College of Obstetricians and Gynecologists Workshop. *Obstetrics and gynecology* 2012; **120**(5): 1181-93.

26. Chen JS, Roberts C, Simpson J, Ford J. Use of hospitalisation history (lookback) to determine prevalence of chronic diseases: impact on modelling of risk factors for haemorrhage in pregnancy. *BMC Med Res Methodol* 2011; **11**(1): 68.

27. Mercuri M, Gafni A. Medical practice variations: what the literature tells us (or does not) about what are warranted and unwarranted variations. *J Eval Clin Pract* 2011; **17**(4): 671-7.

28. Aliaga SR, Smith PB, Price WA, et al. Regional Variation in Late Preterm Births in North Carolina. *Matern Child Health J* 2013; **17**(1): 33-41.

29. Australian Bureau of Statistics. Socio-economic Indexes for Areas (SEIFA). Catalogue 2033.0.55.001. Canberra: Australian Bureau of Statistics; 2006.

30. Australian Bureau of Statistics. Australian Standard Geographical Classification (ASGC) Remoteness Area Correspondences. Catalogue 1216.0.15.003. Canberra: Australian Bureau of Statistics; 2006.

Figure Legends

Figure 1: Risk-adjusted hospital caesarean rates for births at 34 – 36 weeks gestation

Figure 1A: Unadjusted

Figure 1B: Adjusted for casemix

Figure 1C: Adjusted for labour interventions

Figure 1D: Adjusted for hospital characteristics

Table 1: Casemix, labour and hospital characteristics of 20,247 preterm singleton cephalic births in New South Wales, 2007-2011

Variable	26-31 weeks				32-33 weeks				34-36 weeks			
	CS n=1042	(%)	No CS n=863	(%)	CS n=1020	(%)	No CS n=990	(%)	CS n=5897	(%)	No CS n=10435	(%)
Casemix												
Maternal age												
12-19 years	35	(3.4)	61	(7.1)	35	(3.3)	62	(6.3)	125	(2.1)	552	(5.3)
20-34 years	717	(68.8)	593	(68.7)	682	(66.9)	734	(74.1)	3809	(64.6)	7725	(74.0)
35-54 years	290	(27.9)	209	(23.2)	303	(29.7)	194	(19.6)	1959	(36.3)	2157	(20.7)
Parity												
Para 0	540	(52.0)	451	(52.3)	457	(44.8)	498	(50.5)	2407	(40.9)	5100	(49.0)
Para 1	213	(20.5)	217	(25.2)	280	(27.5)	242	(24.5)	1830	(31.1)	2805	(26.9)
Para 2+	286	(27.5)	194	(22.6)	283	(27.75)	246	(25.0)	1646	(27.9)	2508	(24.1)
Born in Australia	714	(68.5)	593	(68.7)	689	(67.6)	692	(69.9)	4157	(70.5)	7351	(70.5)
Patient financial status												
Public	795	(76.4)	710	(82.4)	785	(77.4)	830	(84.2)	3395	(57.8)	7350	(70.8)
Private	246	(26.6)	152	(17.6)	229	(22.6)	156	(15.8)	2478	(42.2)	3026	(29.2)
Smoking in pregnancy	188	(18.3)	200	(23.5)	192	(19.1)	246	(25.1)	861	(14.7)	2149	(20.7)
Socioeconomic status[29]												
5th quintile most disadvantaged	225	(24.8)	263	(31.3)	263	(26.2)	225	(26.3)	1298	(22.3)	2716	(26.5)

4th quintile	156	(15.2)	118	(14.1)	143	(14.2)	165	(17.0)	819	(14.0)	1487	(14.5)
3rd quintile	249	(24.2)	169	(20.1)	251	(25.0)	228	(23.5)	135	(23.3)	2453	(23.9)
2nd quintile	148	(14.4)	117	(13.9)	149	(14.8)	155	(16.0)	862	(14.8)	1366	(13.3)
1st quintile least disadvantaged	222	(21.6)	173	(20.6)	199	(19.8)	167	(17.2)	1496	(25.7)	2246	(21.9)
Remoteness of residence[30]												
Urban	773	(74.8)	663	(78.6)	789	(78.4)	737	(75.6)	4291	(73.2)	7417	(71.6)
Inner regional	173	(16.7)	114	(13.5)	152	(15.1)	149	(15.3)	1093	(16.7)	1910	(18.4)
Rural/remote	88	(8.5)	67	(7.9)	66	(6.6)	89	(9.1)	475	(8.1)	1035	(10.0)
Previous caesarean section	262	(25.1)	86	(10.0)	325	(31.9)	75	(7.6)	2505	(42.5)	631	(6.1)
Small for gestational age infant[1]	83	(8.0)	28	(3.2)	103	(10.1)	22	(2.2)	527	(8.9)	312	(3.0)
Maternal diabetes	99	(9.5)	69	(8.0)	168	(16.5)	127	(12.8)	972	(16.5)	1003	(90.6)
Maternal hypertension	512	(49.1)	41	(4.8)	435	(42.7)	89	(9.0)	1778	(30.2)	1104	(10.6)
Placental morbidities[2]	251	(24.1)	61	(7.1)	232	(22.8)	49	(5.0)	989	(16.8)	183	(1.8)
Chronic co-morbidities[3]	89	(8.5)	18	(2.1)	92	(9.0)	30	(3.0)	321	(5.4)	224	(2.2)
Previous preterm birth	195	(19.7)	150	(17.4)	209	(20.5)	197	(19.9)	983	(16.7)	1507	(14.4)
Previous stillbirth	43	(4.1)	26	(3.0)	50	(4.9)	23	(2.3)	156	(2.7)	171	(1.6)
Use of assisted reproductive technology	56	(5.4)	24	(2.8)	51	(5.0)	24	(2.4)	394	(6.7)	336	(3.2)

Stillbirth in current pregnancy	15	(1.5)	99	(11.6)	14	(1.4)	35	(3.6)	52	(0.9)	155	(1.5)
Major congenital abnormality	18	(1.7)	20	(2.3)	18	(1.8)	18	(1.8)	135	(2.3)	193	(1.9)
Preterm prelabour rupture of membranes	213	(20.4)	370	(42.9)	189	(18.2)	474	(47.9)	1130	(19.2)	3730	(35.8)
Labour interventions												
Epidural analgesia in labour	23	(2.2)	81	(9.4)	33	(3.2)	154	(15.6)	676	(11.5)	2362	(22.6)
Induction of labour[4]	41	(3.9)	152	(17.6)	53	(5.2)	166	(16.8)	691	(11.7)	2496	(23.9)
Outcomes												
Severe maternal morbidity	128	(12.3)	24	(2.8)	112	(11.0)	28	(2.8)	382	(6.5)	200	(1.9)
Severe neonatal morbidity	1002	(96.2)	687	(79.6)	755	(74.0)	513	(51.8)	1621	(27.5)	1497	(14.5)

1. <5th percentile birthweight for gestational age
2. Placenta praevia, placenta accreta or placental abruption
3. Chronic co-morbidities include cardiac, renal, thyroid and autoimmune diseases, and asthma[26]
4. Induction of labour with oxytocin and/or prostaglandin

Table 2: Hospital characteristics

		26-31 weeks N(%)	32-33 weeks N(%)	34-36 weeks N(%)
Total Hospitals		7 (100)	12 (100)	51 (100)
Hospital annual pre term birth volume	<50	0	0	26 (51.0)
	50-99	0	0	13 (25.5)
	100-199	1 (14.3)	6 (50)	6 (11.8)
	200+	6 (85.7)	6 (50)	6 (11.8)
Hospital region	Urban	7 (100)	12 (100)	31 (62.7)
	Rural	0	0	19 (37.3)
Obstetric training capability[1]	Primary	7 (100)	8 (66.7)	8 (15.7)
	Secondary	0	4 (33.3)	19 (37.2)
	No Training	0	0	24 (47.1)
Hospital status	Public	7 (100)	12	36 (60.6)
	Private	0	0	15 (29.4)
Annual hospital rates for preterm births (mean(SD))				
	Caesarean sections under general anaesthetic	31 (9)	32 (7)	27 (11)
	Epidural analgesia in labour	14 (4)	13 (4)	17 (11)
	Induction of labour	19 (5)	13 (5)	17 (5)

1. Primary = tertiary obstetric training hospitals; Secondary= large district hospitals that host obstetric registrars

Table 3: Association between risk-adjusted hospital caesarean section rates

Hospital caesarean section rate	Severe maternal morbidity			Severe neonatal morbidity		
	OR	**(95% CI)**	**p-value**	**OR**	**(95% CI)**	**p-value**
26-31 weeks gestation			0.05			0.02
1st tertile (lowest)	Ref.			Ref.		
2nd tertile	1.07	(0.71 - 1.63)		1.60	(1.13 - 2.27)	
3rd tertile	0.64	(0.39 - 1.02)		1.51	(1.05 - 2.16)	
32-33 weeks gestation			0.84			0.17
1st tertile (lowest)	Ref.			Ref.		
2nd tertile	0.86	(0.44-1.67)		0.79	(0.48 - 1.29)	
3rd tertile	1.01	(0.50-2.03)		1.19	(0.69-2.05)	
34-36 weeks gestation			0.53			0.86
1st quintile (lowest)	Ref			Ref.		
2nd quintile	1.01	0.71-1.43		0.95	0.64-1.42	
3rd quintile	0.80	0.57-1.11		1.04	0.72-1.49	
4th quintile	0.93	0.67-1.31		0.93	0.63-1.36	
5th quintile	1.05	0.75-1.48		1.16	0.78-1.72	

Figure 1: Risk-adjusted hospital caesarean rates for births at 34 – 36 weeks gestation

Figure 1A: Unadjusted

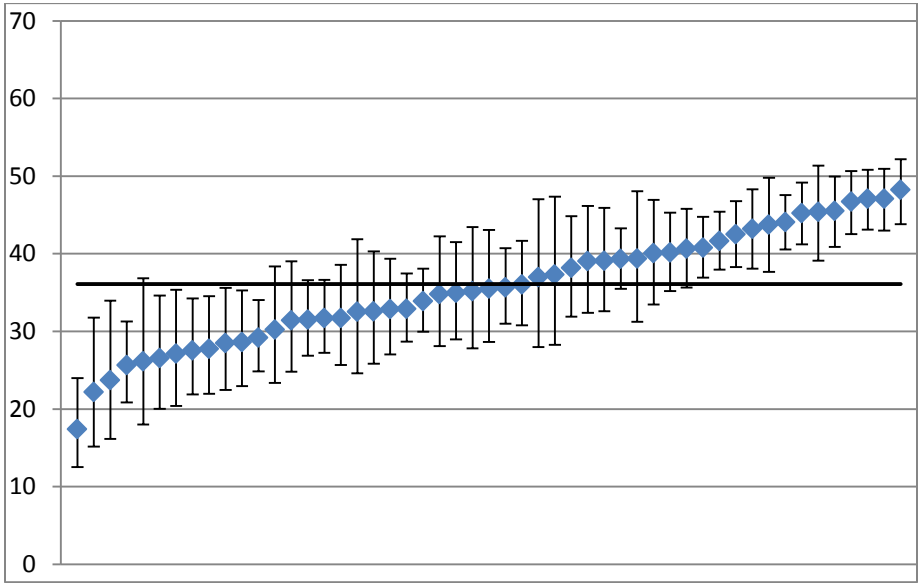


Figure 1B: Adjusted for casemix

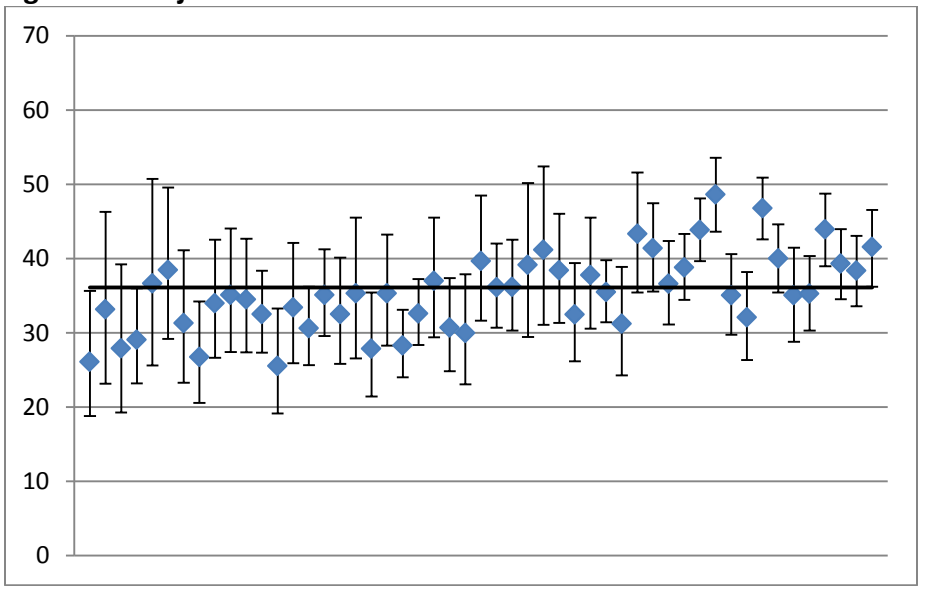


Figure 1C: Adjusted for labour interventions

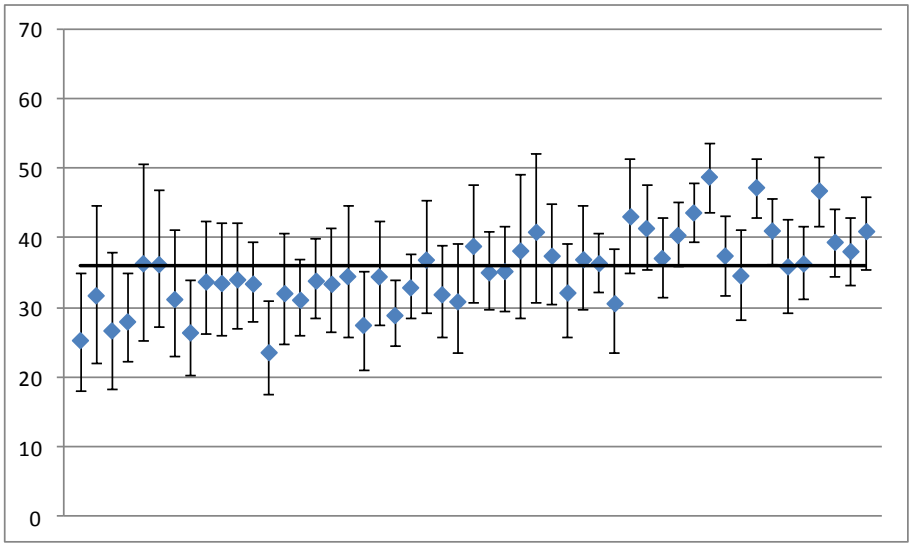
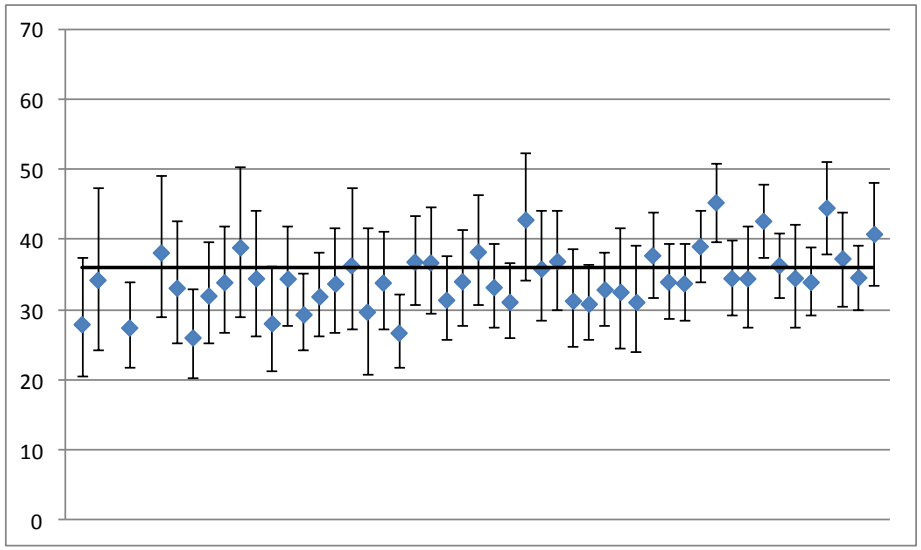


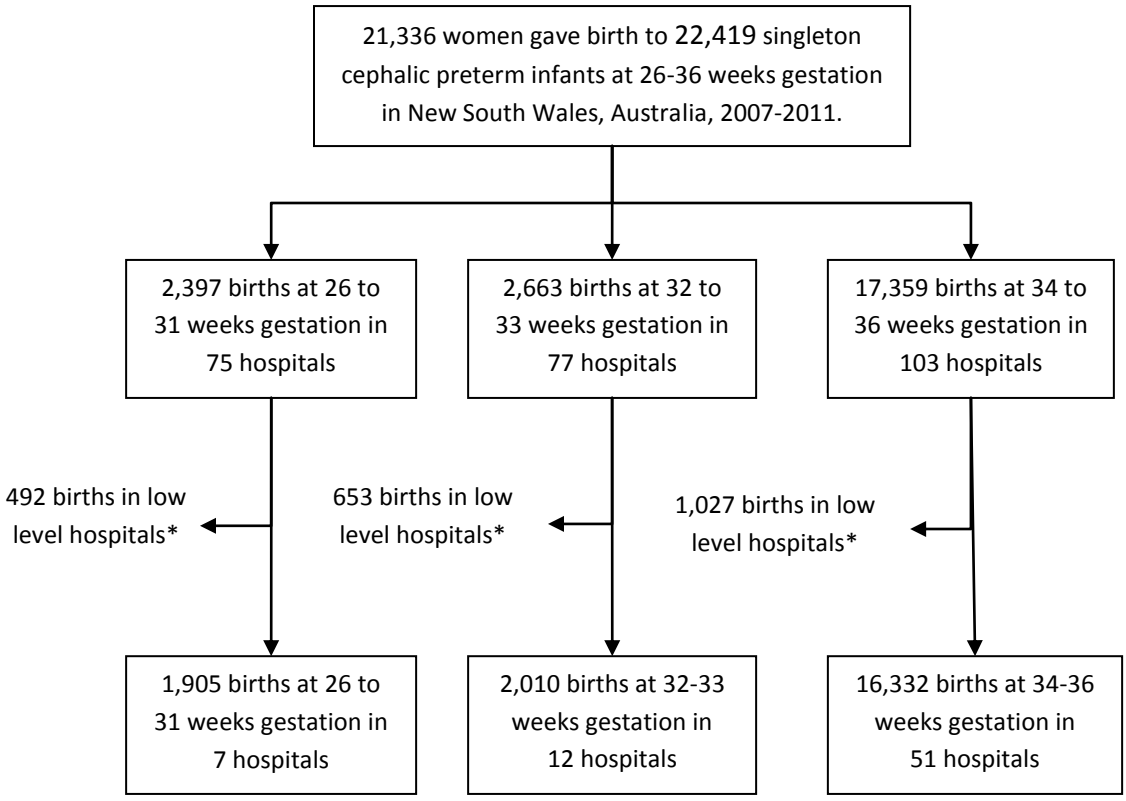
Figure 1D: Adjusted for hospital characteristics



Appendices

Supplementary Information

Supplementary Figure S1: Selection of study population of preterm cephalic singleton births



* Births in hospitals that do not have the service capability to manage infants of this gestation

Figure S2: Risk-adjusted hospital caesarean section rates for births at 26 – 31 weeks gestation

Figure S2A: Unadjusted

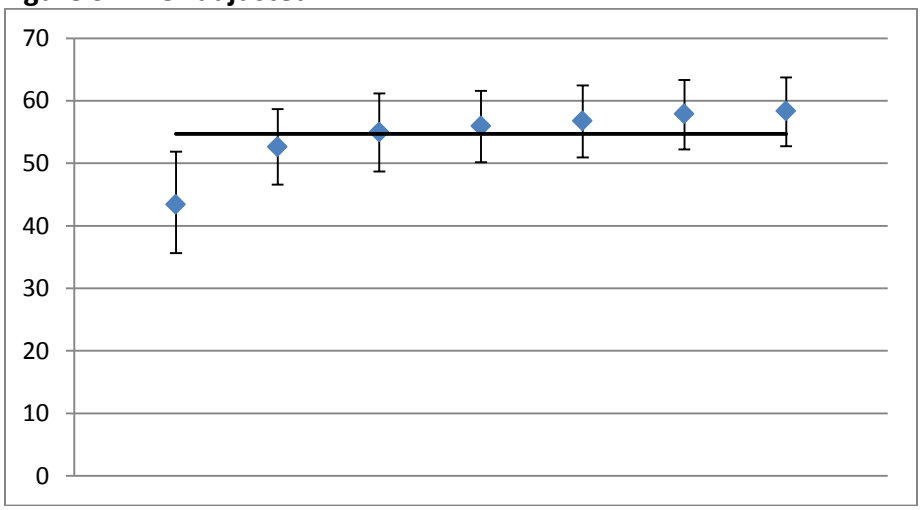


Figure S2B: Adjusted for casemix

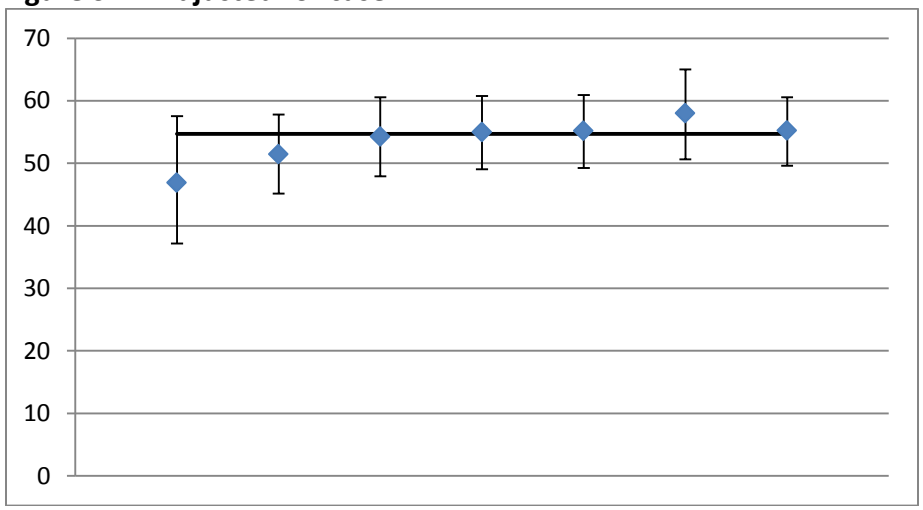


Figure S2C: Adjusted for labour interventions

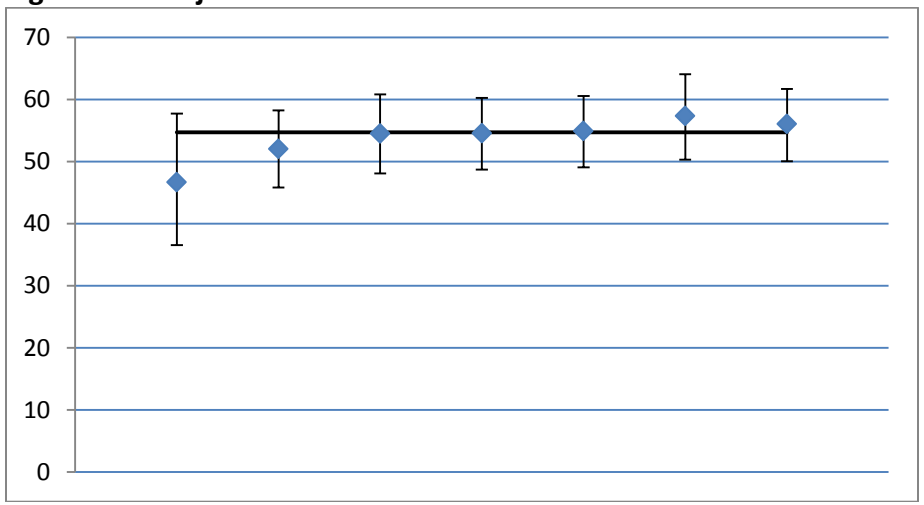


Figure S2D: Adjusted for hospital characteristics

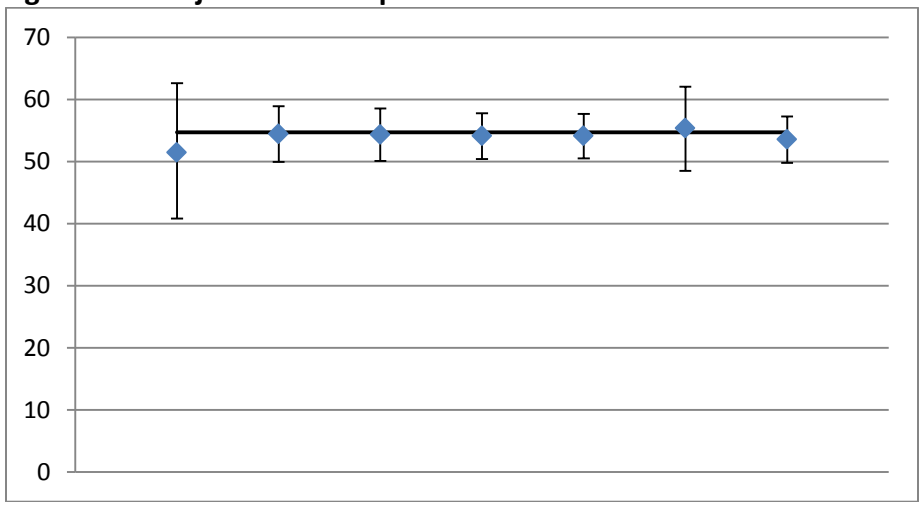


Figure S3: Risk-adjusted hospital caesarean section rates at 32 – 33 weeks gestation

Figure S3A: Unadjusted

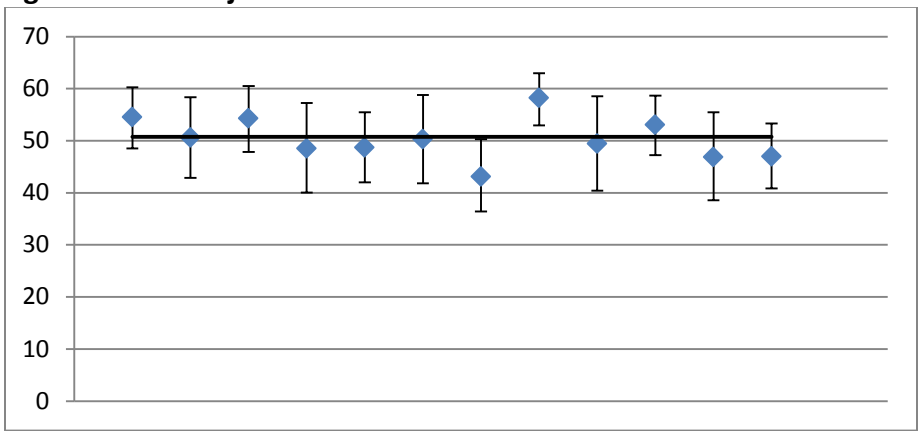


Figure S3B: Adjusted for casemix

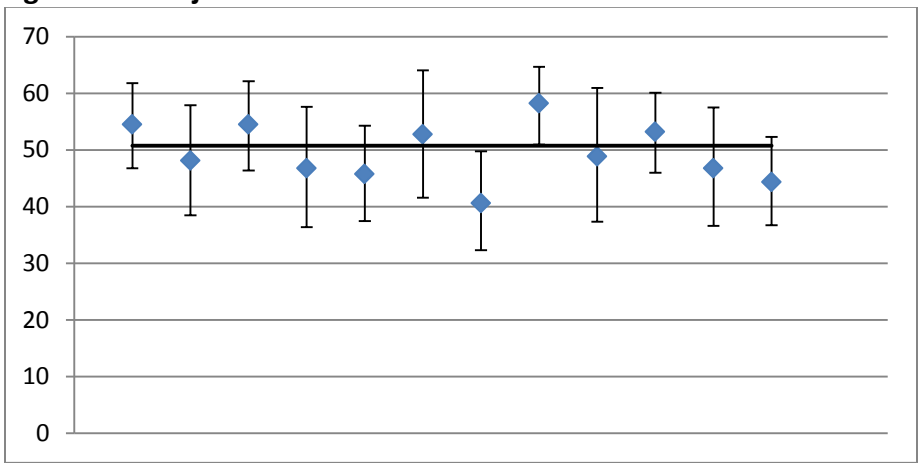


Figure S3C: Adjusted for labour interventions

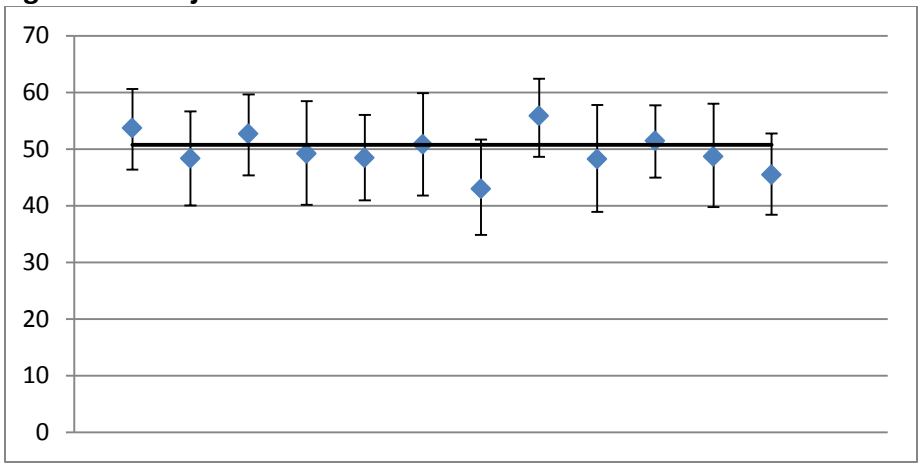
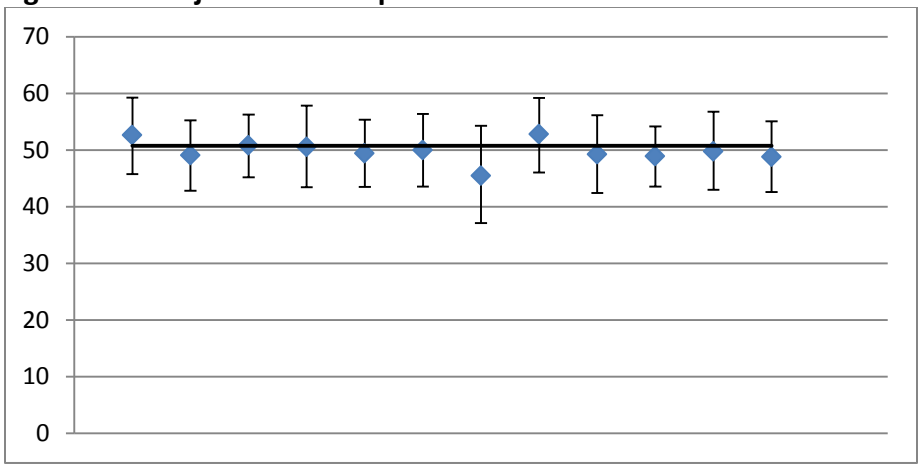


Figure S3D: Adjusted for hospital characteristics



Supplementary Figure S4: Scatter plot of association between risk-adjusted hospital caesarean section rates and hospital severe maternal morbidity rates for births at 26-31 weeks gestation

Figure S4A: Severe maternal morbidity

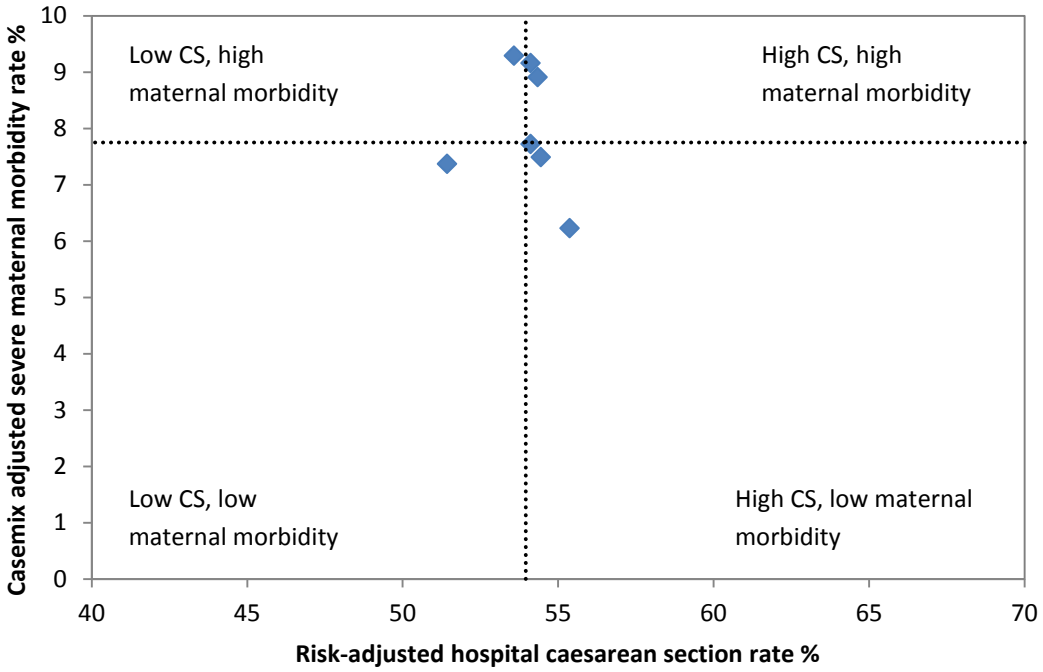


Figure S4B: Severe neonatal morbidity

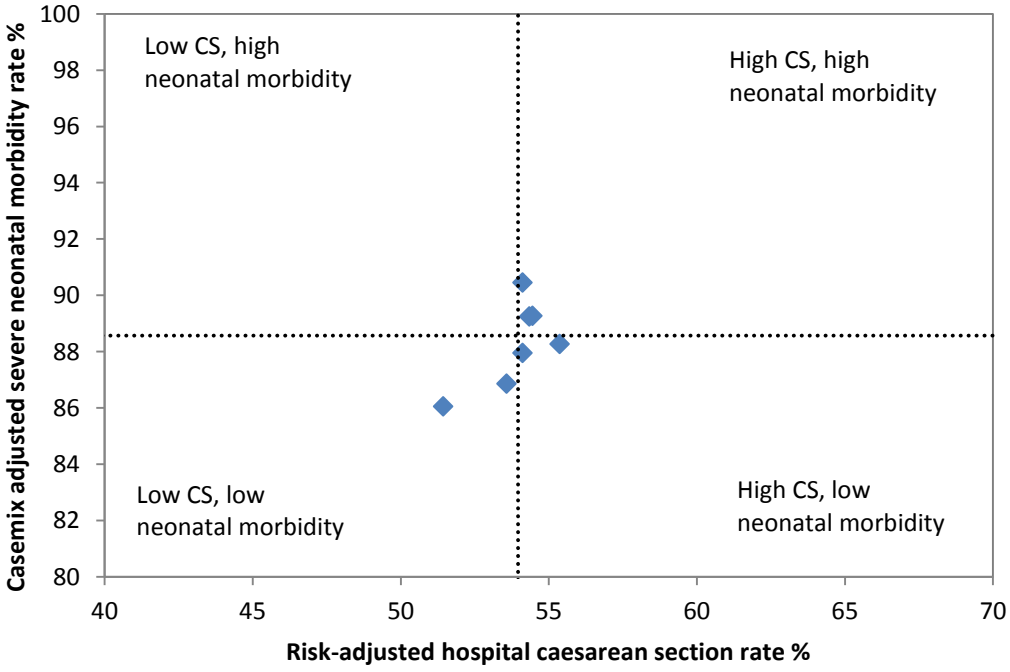


Figure S4 legend: Dashed lines indicate mean rates. CS; caesarean section

Supplementary Figure S5: Scatter plot of association between risk-adjusted hospital caesarean section rates and hospital severe maternal morbidity rates for births at 32-33 weeks gestation

Figure S5A: Severe maternal morbidity

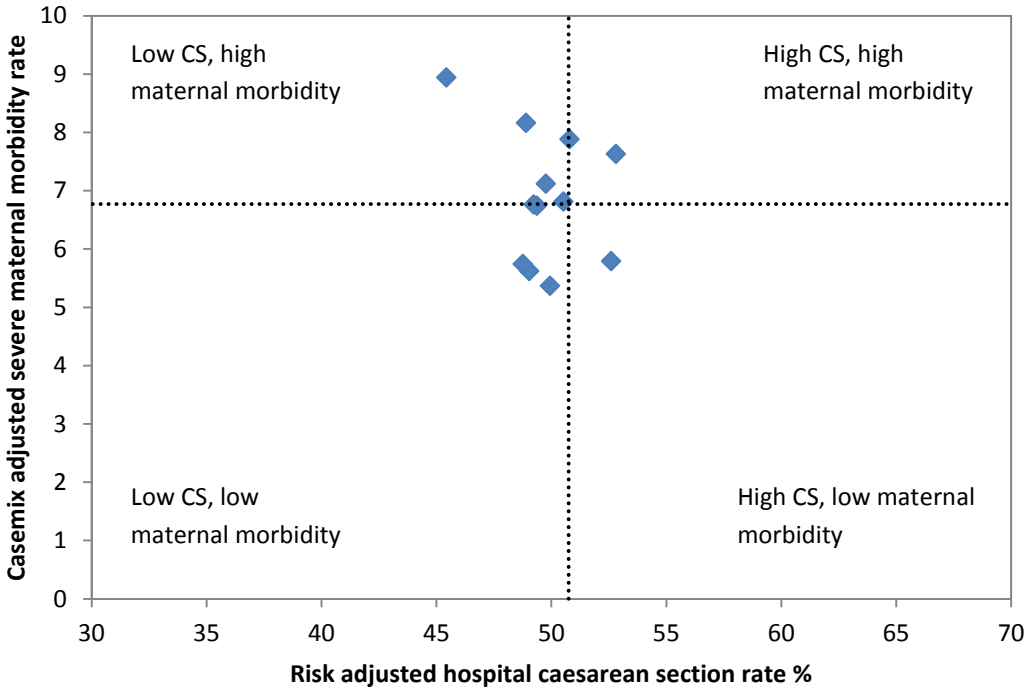


Figure S5B: Severe neonatal morbidity

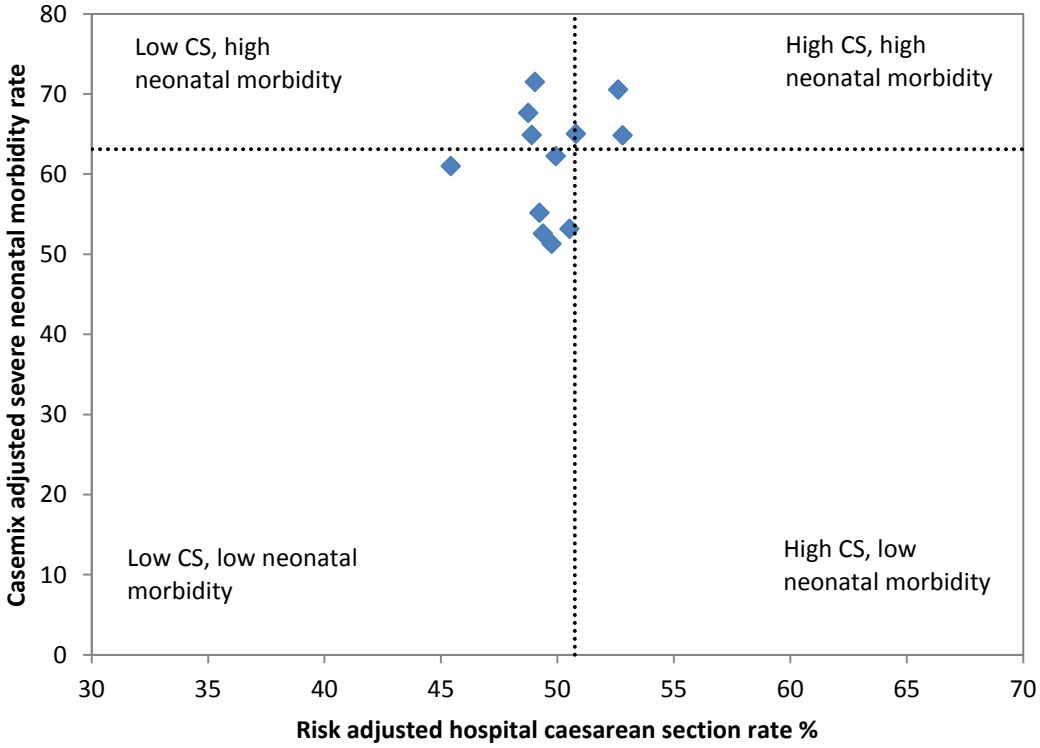


Figure S5 legend: Dashed lines indicate mean rates. CS; caesarean section

Supplementary Figure 6: Scatter plot of association between risk-adjusted hospital caesarean section rates and hospital severe maternal morbidity rates for births at 34-36 weeks gestation

Figure S6A: Severe maternal morbidity

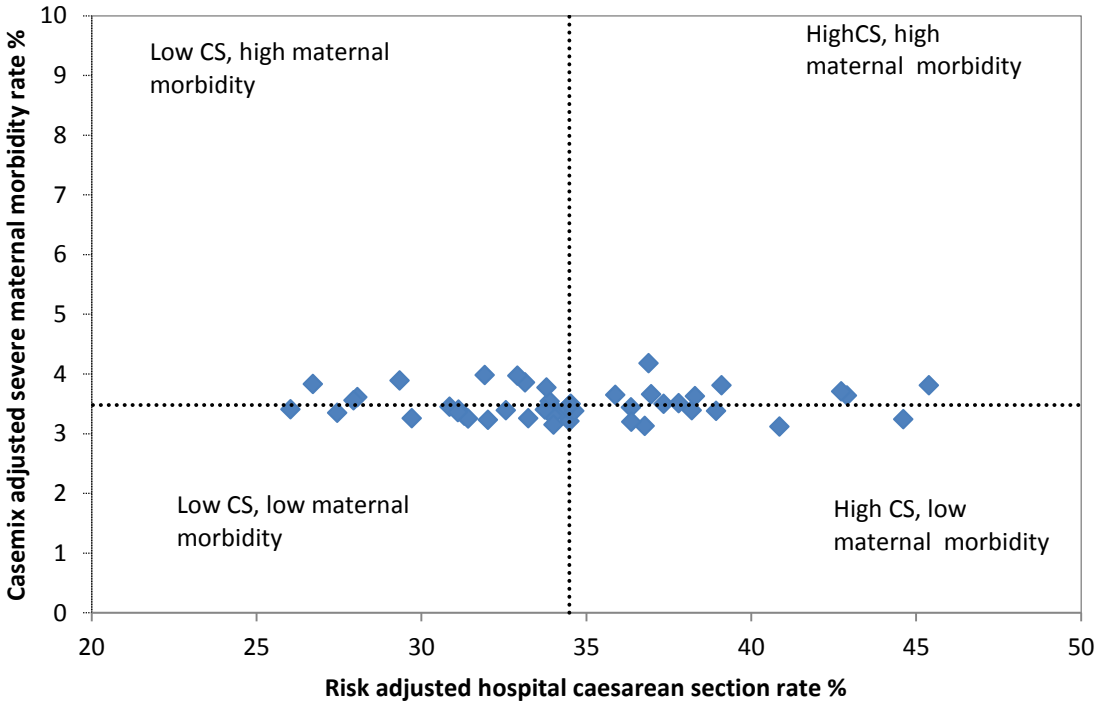


Figure S6B: Severe neonatal morbidity

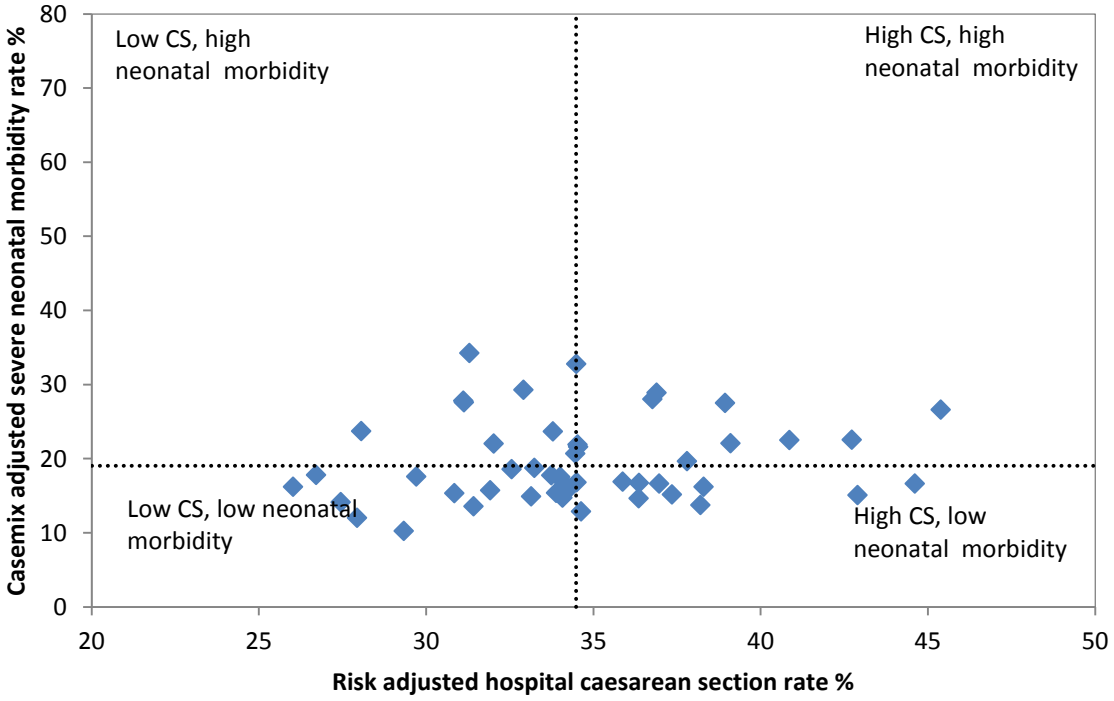


Figure S6 legend: Dashed lines indicate mean rates. CS; caesarean section

Table S1: Adjusted odds ratios for caesarean section among women delivering at 26-31 weeks gestation

Adjustment Factors	OR	95% CI	p-value
Casemix			
Parity			0.015
Para 0	0.81	0.54 - 1.21	
Para 1	0.71	0.47 - 1.09	
Para 2	Ref.		
Para 3+	1.37	0.86 - 2.19	
Private vs public patient	1.58	1.16 - 2.17	0.004
Previous caesarean section*	4.08	2.82 - 5.92	<0.0001
Small for gestational age*	6.54	3.00 - 14.29	<0.0001
Hypertension*	25.64	17.24 - 38.46	<0.0001
Placental morbidity*	7.75	5.43 - 11.11	<0.0001
Other chronic co-morbidity*	2.29	1.20 - 4.37	0.012
ART use*	1.93	1.02 - 3.64	0.042
Stillbirth*	0.04	0.02 - 0.11	<0.0001
PPROM*	0.60	0.46 - 0.78	0.0001
Labour interventions			
Epidural analgesia in labour*	0.29	0.16 - 0.55	0.0001
Induction of labour*	0.56	0.32 - 0.97	0.013
Hospital characteristics			
Hospital caesarean section under general anaesthesia rate	0.98	0.97 - 1.00	0.017

* Compared with not having the specified condition or intervention

ART assisted reproductive technology; PPROM preterm prelabour rupture of the membranes

Table S2: Adjusted odds ratios for caesarean section among women delivering at 32-33 weeks gestation

Adjustment Factors	OR	95% CI			p-value
Casemix					
Private vs public patient	1.67	1.23	-	2.27	0.001
Previous caesarean section*	9.26	6.58	-	13.16	<0.0001
Small for gestational age*	6.13	3.29	-	11.36	<0.0001
Hypertension*	9.35	6.76	-	12.99	<0.0001
Placental morbidity*	9.09	6.25	-	13.16	<0.0001
Other chronic co-morbidity*	2.34	1.35	-	4.07	0.003
Previous spontaneous preterm birth*	0.35	0.24	-	0.51	<0.0001
Previous stillbirth*	2.12	1.10	-	4.08	0.024
Stillbirth in current pregnancy*	0.22	0.09	-	0.52	0.006
PPROM*	0.47	0.36	-	0.61	<0.0001
Labour interventions					
Epidural analgesia in labour*	0.31	0.19	-	0.49	<0.0001
Induction of labour*	0.33	0.21	-	0.52	<0.0001
Hospital characteristics					
Hospital preterm induction of labour rate	0.97	0.95	-	1.00	0.047

* Compared with not having the specified condition or intervention
PPROM preterm prelabour rupture of the membranes

Table S3: Adjusted odds ratios for caesarean section among women delivering at 34-36 weeks

Adjustment Factors	OR	95% CI			p-value
Casemix					
Maternal age					<0.0001
<20 yrs	Ref.				
20-34 yrs	1.59	1.25	-	2.01	
35-39 yrs	1.92	1.48	-	2.48	
40-54 yrs	2.90	2.14	-	3.94	
Parity					<0.0001
Para 0	Ref.				
Para 1	0.46	0.41	-	0.52	
Para 2	0.51	0.44	-	0.59	
Para 3+	0.46	0.39	-	0.55	
Private vs public patient	1.76	1.55	-	2.00	<0.0001
Smoking in pregnancy*	0.87	0.77	-	0.98	0.027
Previous caesarean section*	23.81	20.83	-	27.03	<0.0001
Small for gestational age*	4.26	3.53	-	5.10	<0.0001
Diabetes*	1.81	1.59	-	2.06	<0.0001
Hypertension*	4.29	3.83	-	4.81	<0.0001
Placental morbidity*	18.87	15.63	-	22.73	<0.0001
Other chronic co-morbidity*	2.61	2.07	-	3.29	<0.0001
Previous preterm birth*	0.58	0.50	-	0.67	<0.0001
Previous stillbirth*	2.29	1.65	-	3.17	<0.0001
ART use*	1.35	1.09	-	1.66	0.006
Stillbirth in current pregnancy*	0.37	0.24	-	0.58	<0.0001
PPROM*	0.59	0.53	-	0.65	<0.0001
Major congenital abnormality*	1.57	1.18	-	2.11	0.002
Gestational age					<0.0001
34 weeks	Ref.				
35 weeks	0.80	0.70	-	0.91	
36 weeks	0.76	0.67	-	0.85	
Labour interventions					
Epidural analgesia in labour*	0.46	0.41	-	0.52	<0.0001
Induction of labour*	0.64	0.56	-	0.72	<0.0001
Hospital characteristics					
Annual preterm birth volume					0.11
0-49	Ref.				
50-99	1.15	0.96	-	1.37	
100-199	1.24	0.98	-	1.56	
200+	1.31	1.02	-	1.67	
Hospital caesarean section performed under general anaesthesia rate	0.99	0.99	-	1.00	0.002

* Compared with not having the specified condition
ART assisted reproductive technology; PPROM preterm prelabour rupture of the membranes