creative commons
COMMONS DEED

저작자표시-비영리-변경금지 2.0 대한민국

이용자는 아래의 조건을 따르는 경우에 한하여 자유롭게

- 이 저작물을 복제, 배포, 전송, 전시, 공연 및 방송할 수 있습니다.

다음과 같은 조건을 따라야 합니다:

저작자표시. 귀하는 원저작자를 표시하여야 합니다.

비영리. 귀하는 이 저작물을 영리 목적으로 이용할 수 없습니다.

변경금지. 귀하는 이 저작물을 개작, 변형 또는 가공할 수 없습니다.

- 귀하는, 이 저작물의 재이용이나 배포의 경우, 이 저작물에 적용된 이용허락조건을 명확하게 나타내어야 합니다.
- 저작권자로부터 별도의 허가를 받으면 이러한 조건들은 적용되지 않습니다.

저작권법에 따른 이용자의 권리는 위의 내용에 의하여 영향을 받지 않습니다.

이것은 이용허락규약(Legal Code)을 이해하기 쉽게 요약한 것입니다.

Disclaimer

dCollection

연세대학교
YONSEI UNIVERSITY

Does improved quality of care affect maternal health outcomes? Focusing on adequate prenatal care, off-hours delivery, access to labor facilities, and severe maternal morbidity

Jin Young Nam

Department of Public Health

The Graduate School, Yonsei University

연세대학교
YONSEI UNIVERSITY

Does improved quality of care affect maternal health outcomes? Focusing on adequate prenatal care, off-hours delivery, access to labor facilities, and severe maternal morbidity

A Dissertation Submitted to
the Department of Public Health,
the Graduate School, Yonsei University
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

Jin Young Nam

June 2017

연세대학교
YONSEI UNIVERSITY

This certifies that the Dissertation of ***Jin Young Nam*** is approved.

_____

Eun-Cheol Park: Thesis Supervisor

_____

Sang Gyu Lee: Thesis Committee Member #1

_____

Chung Mo Nam: Thesis Committee Member #2

_____

Sohee Park: Thesis Committee Member #3

_____

Sung In Jang: Thesis Committee Member #4

Department of Public Health

The Graduate School, Yonsei University

June 2017

연세대학교
YONSEI UNIVERSITY

Acknowledgments

For God did not give us a spirit of timidity, but a spirit of power, of love and of self-discipline.

2 Timothy 1:7

I have come a long way until today. Although the process was not easy, I am very grateful for this dissertation and completion of my degree under the grace of my father God.

My biggest thanks go to Prof. Eun-Cheol Park for providing me with the opportunity to study and work at Yonsei University. I sincerely admire his passion for research, depth of knowledge, intuition, and vision and insight for the future. I owe much of my pursuit of a PhD to him. Without his encouragement, guidance, and interest in public health policy and management, I would not pursue this theme.

I am also grateful to Prof. Chung Mo Nam who has been a selfless person for students since I first expressed an interest in statistics. I will appreciate and remember his encouragement and advice for long time. I really give thanks to Prof. Sang Gyu Lee who gave me intellectual stimulation and courage to go deeper into women's studies. He has taught me how to make a logical way and way for deepest research. I would like to thank Prof. Sohee Park who is a role model for

연세대학교
YONSEI UNIVERSITY

working women for her kind support of this research, and I will continue admiring her passion, challenge, and work-family life balance. I am thankful to Prof. Sung-In Jang for his sincere advice, thorough support, encouragement, and cooperative spirit.

I sincerely thank Prof. Seung Hum Yu who gave me the first opportunity to study in the public health area. I really thank Prof. Tae Hyun Kim who taught me social-economic knowledge and kindly helped me always.

Furthermore, I really thank pastor Sunkeun Park who provided intercessory prayer. Through his pray and encouragement, I could complete this course.

I would like to thank my colleagues: Jaeyong Shin, Joo Eun Lee, Yoon Soo Choy, Jin-Hyeong Kim, Seung Ju Kim, Young Choi, Sung Youn Chun, Hyo Jung Lee, Ye Seol Lee; Juyeong Kim, Yeong Jun Ju, Woorim Kim, Sang Ah Lee, Hyo Jeong Yoon, Young Dae Cho, Nam Kyung Lee, Ji Eun Jang, So Yeon Oh, Ji Eun Yang, Won Jung Chae, Dong Woo Choi; and also thank my prior colleagues: Jeong Lim Kim, Jae-Hyun Kim, Suk-Yong Jang, Kyoung Hee Cho, Kyu-Tae Han, Tae -Hoon Lee, Hye Ki Park, Seo Yoon Lee, Tae Kyung Kim, and In Seon Hyun, I truly enjoyed working with you. Additionally, I would especially like to thank Ms. Seung Hee Park and Jung Yu. I sincerely appreciate their professional administrative ability, and accurate advice and support when I was in trouble.

Last, my only lifetime partner Kyu Seop Seo who always makes me

연세대학교
YONSEI UNIVERSITY

happy, I fully respect, honor, and love you. My adorable little daughter Yesol Seo, I really love you, and thank you for understanding your mother. Above all, I would like to express my gratitude to my mother and father, and mother-in-law and father-in-law from all my heart. I owe you a great debt of gratitude.

June 2017

Jin Young Nam

연세대학교
YONSEI UNIVERSITY

TABLE OF CONTENTS

연세대학교
YONSEI UNIVERSITY

연세대학교
YONSEI UNIVERSITY

List of Tables

연세대학교
YONSEI UNIVERSITY

List of Figures

연세대학교
YONSEI UNIVERSITY

Abstract

Does improved quality of care affect maternal health outcomes?
Focusing on adequate prenatal care, off-hours delivery, access to labor facilities, and severe maternal morbidity

Background: Even though most Korean births are delivered in health facilities with skilled birth professionals in attendance, the maternal mortality ratio, which is an indicator of quality of maternal care, is still higher compared with the average for OECD countries. The majority of maternal deaths occur during labor, childbirth, and the postpartum period; therefore, it is necessary to find the risk factors influencing maternal mortality during and after delivery, and to develop replicable indicators of maternal mortality in cases of rare events, such as severe maternal morbidity. However, there have been few studies of severe maternal morbidity during delivery hospitalization as indicators of quality of maternity care in Korea.

Objectives: This study identified the relationship between effectiveness of adequate prenatal care, accessibility of labor facilities, and timing of off-hours delivery as quality factors, and individual, obstetric, and provision factors, and severe maternal morbidity. In addition, this analysis estimated whether severe maternal morbidity was associated with postpartum hospital readmission, adjusting for all quality, individual, obstetric, and

연세대학교
YONSEI UNIVERSITY

provision factors.

Methods: Data were extracted from the Korean National Health Insurance Service-National Sample Cohort for 91,767 cases of delivery that were delivered during 2003–2013. Severe maternal morbidity status was determined using the Center for Disease Control and Prevention's algorithm including the diagnosis and procedure code during delivery hospitalization. Postpartum readmission rates within 6 weeks after delivery were determined. A generalized estimating equation (GEE) model with logit link was performed for the relationship with severe maternal morbidity and women's factors to estimate adjusted odds ratios. Cox proportional hazards models with robust variance-covariance matrixes to account for repeated measures of individuals were used for the postpartum readmission and severe maternal morbidity to calculate adjusted hazard ratios.

Results: Of the 91,767 delivery cases, 2,248 (2.45%) had severe maternal morbidity. In the GEE model, severe maternal morbidity was higher in women who had inadequate prenatal care than in those who had adequate prenatal care (odds ratio (OR) 1.39, 95% CI 1.08-1.79), women who had weekday nighttime or weekend delivery had a higher risk of severe maternal morbidity compared with those who had weekday daytime delivery (OR 1.18, 95% CI 1.02-1.38, and OR 1.70, 95% CI 1.37-2.11, respectively). Access to labor facilities was not a statistically significant predictor. For maternal age, women who delivered at extremely young or old ages had high risks of severe maternal morbidity, which showed a J-shaped distribution through the whole age range. Women who had the

연세대학교
YONSEI UNIVERSITY

lowest level of income, who had cesarean section delivery, who were nulliparous, who had twins or more than triplet births had high risks of severe maternal morbidity. In Cox analysis, women with severe maternal morbidity had higher risks of postpartum readmission than those without severe maternal morbidity (hazard ratio (HR) 2.29, 95% CI 1.70-3.10).

Conclusion: Inadequate prenatal care delivery was associated with the occurrence of severe maternal morbidity during delivery hospitalization. In addition, weekday nighttime or weekend delivery was related to the risk of severe maternal morbidity. Moreover, women with severe maternal morbidity had higher risks of postpartum readmission. Therefore, policy makers should consider making quality indicators for timely, adequate, and sufficient visits during pregnancy and should monitor adequacy of prenatal care to prevent severe maternal morbidity and to improve maternal quality of health care; additionally, they should provide financial support and systematically allocate adequate human resources and labor facilities in vulnerable areas, as well as during weekends and night times to improve the quality of intrapartum and postpartum maternity care.

연세대학교
YONSEI UNIVERSITY

Ⅰ. Introduction

1. Study Background

Korea has had a low fertility rate since the early 2000s, and has now recorded the lowest fertility rate among OECD countries with a total fertility rate (TFR) of 1.2 in 2014. As women's social activities and the phenomenon of non- or late marriage have increased, in 2015 Korean women's average age of first birth was 31.2 years old [1]. Increasing age of first birth raises risks of adverse maternal health outcomes such as elderly mothers, preterm birth, obstetric complications, and multiple births due to assisted reproductive technology; as a result, the maternal mortality ratio is higher than the OECD average [2]. To cope with this phenomenon, in 2005 the Korean government instituted the Basic Law on Low-Fertility and Elderly Societies, and established the "Low Fertility and Elderly Society Committee" to officially intervene in the problem of low fertility. However, there is a lack of policies related to low fertility focused on maternity. The United Nations has reported the population indicators of many countries; maternal health outcomes and the maternal mortality ratio are some of the indicators for improving the population quality of childbirth [3]. Yang has reported that it is important to emphasize improving the quality of maternal health and nutrition of early childhood at the population level in Korea [4]. Therefore, it is necessary to measure quality of maternal care to raise fertility rates as well as to improve maternal health.

연세대학교
YONSEI UNIVERSITY

Maternal mortality has been the typical indicator of quality of maternal care. The United Nations (UN) achieved a 75% reduction in the maternal mortality ratio from 1990 to 2015 through global efforts to accomplish the Millennium Development Goal (MDG) [5,6], and have reaffirmed the reduction of maternal mortality as a global priority in the coming decades through adoption of the Sustainable Development Goals (SDGs) [7]. Although these global activities have resulted in higher coverage of skilled birth attendants and antenatal care [8], the maternal death rate was estimated at 289,000 women [9] and the burden of high maternal death is still a relevant public health problem of low-, middle-, and developed countries [10] because pregnant women's health status is not reflected only by mortality indicators [11,12]. Despite most maternal mortality events occurring during labor, childbirth, and the postpartum period [13-16], limited research has examined postpartum care until recently. To end preventable maternal adverse outcomes during delivery or the postpartum period, indicators of quality of maternal care are needed.

Severe maternal morbidity (SMM) has grown in use as an indicator of the quality of obstetrical care. It is difficult to measure the impact of changes in routine obstetrical care on maternal mortality, which is a rare event in absolute terms; therefore SMM is a more useful indicator for evaluation and improvement of maternal health services than maternal mortality ratio [12,17]. SMM can be defined as unintended outcomes

연세대학교
YONSEI UNIVERSITY

of the process of labor and delivery that result in significant short-term or long-term consequences to a woman's health [18]. Although different groups have suggested different definitions and various lists of conditions and complications of SMM [19-22], the concept of SMM is similar to this: "potentially life-threatening conditions during pregnancy, childbirth, or after termination of pregnancy from which maternal near miss cases would emerge" [23,24].

In previous research, several contributing factors for SMM have been identified. Risk factors for SMM have been reported in the following categories: socio-demographic factors include racism [25-27], employment status [28,29], household income [30], and residence in disadvantaged areas [31,32]; obstetric history or performance factors include maternal age [31,33,34], a previous abortion history [30], comorbidities [35], obstetric complications [25,33,36,37], multiple births [38-40], cesarean section delivery [31,33,35], preterm birth [33], prenatal care [30], and use of assisted reproductive techniques [38,40]; provision of health care services includes referral to a tertiary center [41] and hospital volume [36]. However, previous research had less shown that the relationship between adequate prenatal care using objective index or exact day/time of delivery and SMM adjusted individuals, obstetrics, and provisions factors. Ascertaining associated risk factors for SMM enables a better understanding of the problem and serves as a foundation for the development of an effective preventive strategy [33]; therefore it is important to understand the various definitions and risk factors

연세대학교
YONSEI UNIVERSITY

for SMM.

Moreover, SMM often results in high direct medical costs, extended length of hospitalization, and long-term rehabilitation [21,42], yet little is known about postpartum readmission and SMM. A few previous studies showed relationships between mode of delivery, maternal race, comorbidities, or length of stay, and risk of postpartum readmission [43-46]; however, there is scant evidence concerning the association between SMM and postpartum readmission.

Therefore, the aim of this analysis was to explore the risk factors for SMM and to identify the relationship between SMM and postpartum readmission to improve maternal health status and the quality of population-level care, and to increase the rates of reproductive fertility among women in Korea.

연세대학교
YONSEI UNIVERSITY

2. Study Objectives

The purpose of this study was to identify and investigate which factors were associated with SMM. Additionally, the present study investigated whether SMM as a quality of maternal care indicator could affect postpartum readmission as a maternal health outcome. The hypotheses of this study were as follows:

First, quality indicators for maternal care and other contributing factors would be associated with SMM.

Second, SMM as quality indicators would be related to postpartum hospital readmission.

연세대학교
YONSEI UNIVERSITY

Ⅱ. Literature Review

1. Quality of care

1) Definition and components of quality in health care

Several studies reviewed here have defined quality of care [49-55]. Donabedian defined quality of health care as “the application of medical science and technology in a manner that maximizes its benefit to health without correspondingly increasing the risk” [49]. Donabedian asserted that there are three key components for quality care (Structure, Processes, and Outcome) [56], and asserted that these three categories of quality measures are not independent, but are linked in an underlying framework, which means that a good structure promotes good processes and consequently affects good outcomes [57]. IOM's definition indicates that quality of care is the extent to which health care services for individuals and populations are consistent with the desired health outcomes and current medical knowledge [51,58]. The IOM definition of quality care is comprehensive and encompasses three key components of quality: clinical (safe and effective), interpersonal (patient-centered) and contextual (timely, efficient, and equitable) [59]. Roemer and colleagues defined quality of care as the performance of interventions according to standards that are known to be safe, that are affordable by society, and that have the ability to produce an impact on mortality, morbidity, and disability [50]. Leatherman and Sutherland described quality of care for 6 components (Effectiveness, Access and

연세대학교
YONSEI UNIVERSITY

Timeliness, Capacity, Safety, Patient-centeredness, and Disparities). The medical system must have sufficient resources to provide adequate services; therefore, the term “competence” has been added in this concept [54]. Wilson and Goldsmith described quality of care as "the sum of its four components: technical quality (measured by patients' health status improvement), resource consumption (measured by the costs of care), patient satisfaction (measured by patient perception of the subjective or interpersonal aspects of care), and values (measured by the acceptability of any trade-offs that must be made among the three previous outcomes)" [52]. In addition, international organizations are also contributing to the consensus concerning the quality of care categories. The World Health Organization (WHO) reports that improvement of quality and outcomes in the health care system have begun to understand the meaning of “quality” and designing policy interventions and measures to improve outcomes is impossible without an understanding of “quality” [55]. WHO suggests six dimensions of quality, which require that health care be effective, efficient, accessible, acceptable/patient-centered, equitable, and safe. The OECD also presents the components of quality care through the countries that have adopted the Health Care Quality Indicator (HCQI) Project [53]. The dimensions of quality of care are focused on four categories, namely effectiveness, safety, and responsiveness or patient centeredness [53].

연세대학교
YONSEI UNIVERSITY

2) Conceptual framework for quality of care

Quality can be considered using varying models or conceptual frameworks. The research literature has described several models of quality of care [49,59-63]. The most commonly used models are perspective, characteristics, and system models. The perspective models focus on the quality of care as perceived by different constituencies: patients, health care providers, and health care managers [60]. The characteristic models consider quality of care as comprising different characteristics that can vary in importance depending on the type of health care being provided. Characteristic models list the following elements for health care quality: access to care (geographic access, financial access, organizational access, linguistic access, and physical access), social acceptability, relevance, effectiveness, equity, and efficiency [61]. Moreover, the IOM defined quality of care using six main characteristics: safety, effectiveness, patient-centeredness, timeliness, equity, and efficiency. This definition has different stakeholders (women, healthcare providers, or managers), and they have different standpoints on the same characteristics [59]. In the system models, quality of care is related to different dimensions of the health care system and measured at different points in the system. Quality of care has three constituents: the quality of the structure of health care services, the quality of the process (actual health care activity), and quality of the outcome [49]. Recently, Raven and colleagues approached quality of care from various perspectives on

연세대학교
YONSEI UNIVERSITY

maternal health care through a comprehensive analysis of previous literature [64]. They also presented a typology of quality of health care including the dimensions of the health system, characteristics of quality, perspectives of quality, and elements of quality such as provision and experience of the care framework, reproductive health rights approach, and evidence based medicine or practice **(Table 1)**.

연세대학교
YONSEI UNIVERSITY

Table 1. Typology for quality of health care

Model	Quality of Structure	Quality of Process	Quality of Outcomes
Dimensions of health system - Donabedian	· Policy · Resources · Organization · Management system	· Service delivery	· Outputs · Health status
Characteristics of quality - Maxwell	· Accessibility · Availability · Affordability · Relevance to need · Goodness of amenities · Equity · Sustainability	· Appropriateness · Acceptability · Technical competence · Safety · Goodness of interpersonal relationship	· Coverage · Effectiveness · Efficiency · Health impact · User satisfaction
Perspectives of quality - Ovretveit	Client quality ↔ Professional quality ↔ Management quality		
Elements of quality - Hulton et al.	· Human and physical resources · Referral system · Information system	· Use of appropriate technologies · Internationally recognized good practices · Management of emergencies	· Experience of care

Source: Raven JH et al., What is quality in maternal and neonatal health care? Midwifery 2012; 28: e676-e683.

연세대학교
YONSEI UNIVERSITY

2. Quality of maternal health care

During the past two decades, countries worldwide have attempted to ensure high coverage of skilled birth attendance at delivery and antenatal care to reduce morbidity and mortality among mothers and newborn babies [8,65]. As a result, higher coverage of skilled birth attendant and antenatal care puts women and their babies in contact with professionals who can manage uneventful pregnancies, labor, and births, and either prevent, detect, treat, or appropriately refer complications [8]. Additionally, this has resulted in improved rates of birth in health facilities, and a higher proportion of avoidable maternal and perinatal mortality and morbidity have moved health facilities [65]. The outcome of maternal and neonatal care during childbirth in health facilities reflects the overall quality of care provided [65]. Quality of care depends on the available physical infrastructure, supplies, management, human resources and knowledge, skills, and capacity to deal with normal pregnancy, complications, and childbirth including required prompt life-saving intervention [66]. Therefore, it is important to improve the quality of care in health facilities to reduce preventable maternal mortality, and to understand the complex interactions between the experience of mistreatment and lack of support that could affect the experiences and outcomes of women who give birth [67].

To define quality of maternal health care, extra challenges with specific dimensions are needed. Several papers have specifically addressed this point [68-70]. Hulton

연세대학교
YONSEI UNIVERSITY

and colleagues reported a definition of maternal health quality that incorporated the concept of both effective and timely access, and of reproductive health rights: "quality of care is the degree to which maternal health services for individuals and populations increase the likelihood of timely and appropriate treatment for the purpose of achieving desired outcomes that are both consistent with current professional knowledge and uphold basic reproductive rights." There are two significant components of care in this definition: 1) the quality of the provision of care and 2) quality of care as experienced by users. The use of services and outcomes are the result of women's experience of care as well as the provision of care [68]. Pittrof and colleagues suggested four elements of quality of maternity care: 1) most users of maternity services are well; 2) some users with complication of pregnancy or childbirth will develop conditions requiring a higher level of maternity care; 3) maternity care is aimed toward at least two recipients, specifically, the mother and newborn; and 4) non-biomedical factors might be more important than other components of health care in childbirth because of emotionally and culturally sensitive areas. Moreover, the authors asserted that not only clinical outcomes but also satisfaction for providers and experiencers are valued. Additionally, it is important to consider the cost of care for health services and the sustainability of care over time [69]. The COPE (Client Oriented, Provider Efficiency) process developed by Engender Health suggested a framework for improving quality of maternal health with seven client rights

연세대학교
YONSEI UNIVERSITY

and three staff needs [70]. In the framework, seven clients' rights are information; access to services; informed choice; safe services; privacy and confidentiality; continuity of care; and dignity, comfort, and expression of opinion; furthermore, three health care providers' needs are facilitative supervision and management; information, training, and development; and supplies, equipment, and infrastructure. There are two assumptions on this framework: 1) users of health care services are autonomous health care consumers or clients who are responsible for making decision about their own health and have a right to high quality care; and 2) health care providers want to perform their duties well, but without support and resources, they are unable to provide this high quality care [70]. WHO has identified a quality of care framework for maternal and newborn health that integrates Donabedian's model of quality of care for health facilities (1988), and other models' key characteristics of quality of care [55,62,68,71,72], using different elements from the provision of care and the experience of care. Additionally, WHO has advanced health systems by identifying several concepts (service delivery; health workforce; information, medical products, vaccines, and technologies; financing and leadership/governance) creating a structure for health systems analysis and intervention. Based on these developments, the framework presents the concept of quality of care for maternal and newborn health **(Figure 1)**.

연세대학교
YONSEI UNIVERSITY

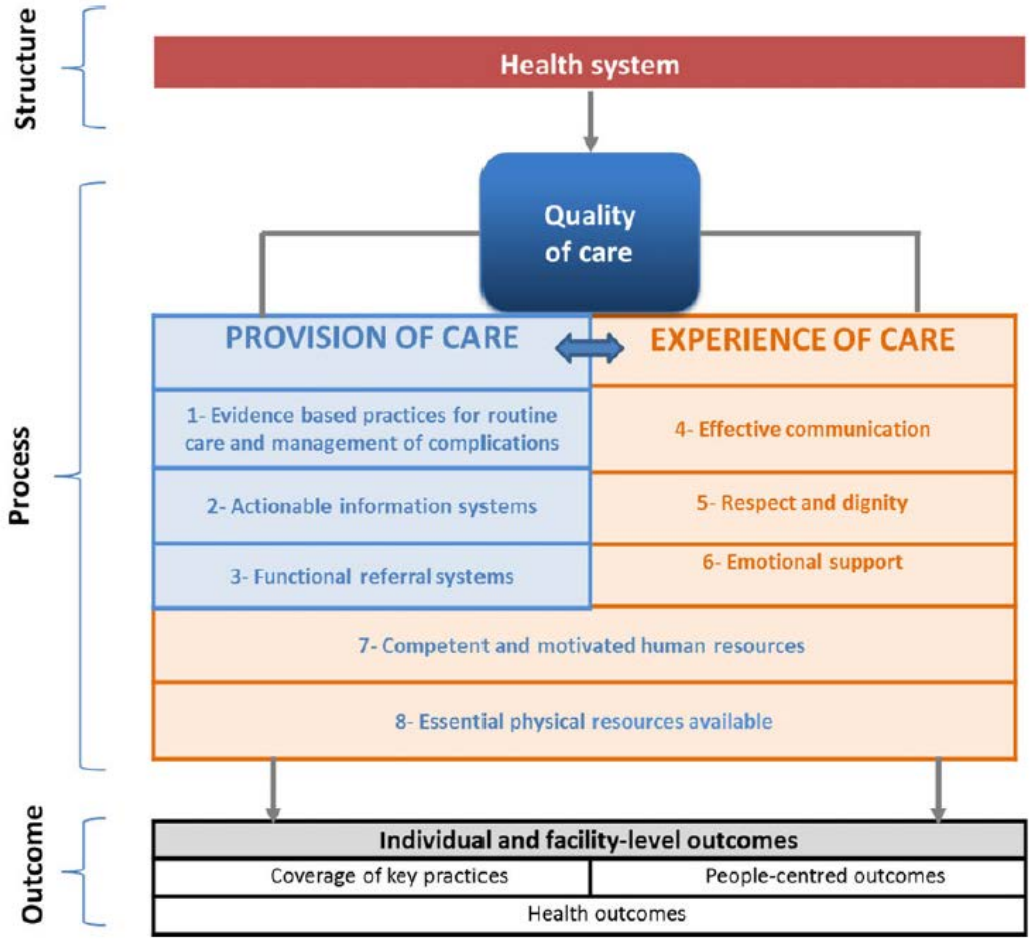

Figure 1. WHO quality of care framework for maternal and newborn health

Source: Tunçalp, Ö et al. Quality of care for pregnant women and newborns-the WHO vision. BJOG. 2015; 122(8): 1045-1049.

연세대학교
YONSEI UNIVERSITY

3. Severe maternal morbidity as quality of maternal health care

Maternal morbidity commonly includes physical and psychological conditions resulting from pregnancy that have an adverse effect on the woman's health, such as maternal death [73]. Although maternal mortality has been the main indicator of maternal health, these tragedies have been compared to the "tip of the iceberg." [73]. All governments and international agencies have recognized reducing the maternal mortality ratio (MMR) globally as an important challenge, and attempted to establish as a target the United Nations MDG 5 [74,75]. Although the developing world faces the greatest challenges in tackling maternal mortality, women continue to die unnecessarily during or after pregnancy in the developed world [76,77]. MMRs are not declining in the developed world, and indeed, in some countries, such as the US, have doubled over the last 20 years [9].

SMM can be thought of as unintended outcomes of the process of labor and delivery that result in significant short-term or long-term consequences to a woman's health, such as hemorrhage, embolism, acute renal failure, stroke, acute myocardial infarction, and other complications [18,21]. Although SMM involves rare conditions, these conditions often produce high direct medical costs, extended length of stay in delivery hospitalization, and long-term rehabilitation [21]. SMM is also a matter of concern for health care providers who are involved in the care and treatment of women during and after pregnancy and an organized national approach for the reduction of maternal

연세대학교
YONSEI UNIVERSITY

morbidity and mortality has recently been called for [78]. Even though prevention and treatment for women can be challenging, SMM can provide clinically relevant measures for quality of maternal care [78,79].

There is considerable variation in definitions of and the constitution of SMM conditions and complications [19-22]. However, whether the terminology used is "severe maternal morbidity" [21], "severe acute maternal morbidity" [80], or "maternal near miss" [24,81,82], most algorithms designed to identify women who have complications at the severe end of the morbidity spectrum have coalesced around indicators of organ system failure [73].

Geller and colleagues identified the severe end of the morbidity spectrum (near miss) using in-depth clinical case reviews by an expert panel to identify cases considered to involve near-miss morbidity [81,82]. They developed a scoring system based on 11 clinical factors. Each factor was coded as a dichotomous variable, but conditions not involving life-threatening morbidity were examined using the clinical classification of these categories as the gold standard.

Recently, the WHO Working Group on Maternal Mortality Morbidity Classifications developed a standard definition and internationally accepted identification criteria for very severe and SMM cases [23,24], and published a guide that presented a standardized "near-miss approach" for improving maternal health care that included identifying cases with severe maternal complications, critical interventions for ICU use,

연세대학교
YONSEI UNIVERSITY

or life-threatening conditions [9]. Hence, maternal near miss or very SMM is defined as "a woman who nearly died but survived a complication that occurred during pregnancy, childbirth, or within 42 days of termination of pregnancy." Additionally, SMM refers to "potentially life-threatening conditions during pregnancy, childbirth, or after termination of pregnancy from which maternal near miss cases would emerge." The identification of maternal near miss cases is based on the presence of 25 criteria regarding organ and system dysfunction via clinical-, laboratory-, and management-based parameters. The approach is comprehensive and may represent an opportunity to combine the timeliness of real-time identification with the large number of diagnoses and procedures put forward in the International Classification of Disease, 9th Revision, Clinical Modification (ICD-9-CM) based algorithms [73]. However, real-time in hospital detection of near-miss cases will require a system to identify women who have various indicators of conditions such as organ system failure. Furthermore, the system will need to be resource-intensive, and it is not clear whether cases could be identified equally well not only in well-equipped hospitals with an information system but smaller sets of health care facilities [73].

Another definition of SMM is based on the ICD-9-CM codes. These are diagnosis and procedure codes recorded at discharge that reflect the events of the hospitalization and are used for billing and other administrative purposes [21]. Several studies have designed algorithms to describe delivery admissions, and more recently

연세대학교
YONSEI UNIVERSITY

postpartum hospitalizations, that could be linked to diagnoses and procedure codes that were thought to indicate severe life-threatening diagnoses, procedures related to life-threatening conditions, or both [21,34,83]. Callaghan and colleagues explained that the concept of using ICD codes is captivating, especially for public health surveillance, in that hospital, state, and nationwide data sets with codes are available [73]. However, the accuracy of obstetric settings' codes is variable [84] and it is impossible to capture all severe morbid events by codes. Moreover, maternal morbidity defined by ICD-9-CM codes has not been validated compared with a gold standard for SMM, and could not be used for real-time identification and review, even though the codes are relatively rare and provide well-characterized diagnoses and procedures better than general obstetric codes [73].

Other recent reports have defined the following 2 screening criteria for SMM: 1) pregnant or postpartum women who have been admitted to the intensive care unit (ICU) and/or 2) have received ≥ 4 units of packed red blood cells because of their high sensitivity and specificity for identification of cases of SMM [73,85,86]. Most recently, there is a definition using *new gold standard clinical guidelines* to identify true cases of SMM and to utilize the recommended multidisciplinary committee approach to determine the incidence of and characterized opportunities for improvement in maternal care. [87]. The definition includes the following criteria: 1) International Classification of Diseases, 9th Revision codes for severe illness as identified by the Centers for Disease Control and

연세대학교
YONSEI UNIVERSITY

Prevention [21]; 2) prolonged length of stay (≥ 4 days for vaginal delivery, ≥ 6 days for cesarean delivery), 3) ICU admission; 4) transfusion of ≥ 4 U of packed red blood cells; or 5) hospital readmission within 30 days of discharge [88].

In previous studies, several factors contributing to SMM have been identified (Table 2). These factors include the following categories: socio-demographic factors such as racism [25-27], employment status [28,29], household income [30], and residence in disadvantaged areas [31,32]; obstetric history or performance factors such as maternal age [31,33,34], a previous abortion history [30], comorbidities [35], obstetric complications [25,33,36,37], multiple births [38-40], cesarean section delivery [31,33,35], preterm birth [33], prenatal care [30], and use of assisted reproductive techniques [38,40]; provision of health care services such as referral to a tertiary center [41] and hospital volume [36]. Ascertaining factors associated with SMM enables a better understanding of the problem and serves as a foundation for the development of an effective preventive strategy [33]; therefore it is important to understand the various definitions and contributing factors in SMM.

연세대학교
YONSEI UNIVERSITY

Table 2. Summary of previous literatures

Authors	Study population	Study Design	SMM criteria*	Outcome variables†	Interesting variables	Main finding	Relationship with SMM
Kominarek MA et al. (2017)	US	Retrospective cohort	Others	SMM	Obstetric hemorrhage	Hemorrhage-relate SMM is not differ after implication of provider training initiative	Negative
Siddiqui M et al. (2017)	US	Retrospective cohort	Others	SMM, MMR	Racial disparity	Asian women had higher rates of maternal mortality	Positive
Howell EA et al. (2017)	US	Cross-sectional	CDC	SMM	Ethnic disparity	Hispanic had higher rate of SMM	Positive
Santana DS et al. (2016)	Multi-countries	Cross-sectional	WHO	Near-miss, SMM, maternal death	Multiple pregnancy	Twin pregnancy is related to SMM, maternal death	Positive
Norhayati MN et al. (2016)	Malaysia	Cross-sectional	WHO	SMM	General factors	SMM is related to maternal age, past pregnancy complications, cesarean delivery, preterm birth, referred to tertiary center	Positive

* CDC: Center for Disease. WHO: World Health Organization, Others include New Gold standard clinical guidelines.
† SMM: Severe maternal morbidity, SAMM: Severe acute maternal morbidity, MMR: Maternal mortality rate.

연세대학교
YONSEI UNIVERSITY

Table 2. Summary of previous literatures *(continued)*

Authors	Study population	Study Design	SMM criteria	Outcome variables	Interesting variables	Main finding	Relationship with SMM
Witteveen T et al. (2016)	Netherlands	Population-based cohort study	Others	SAMM	Multiple pregnancy	Multiple pregnancy is higher risk of SAMM	Positive
Howell EA et al. (2016)	US	Cross-sectional	CDC	SMM	Racial disparity	SMM is related to racial disparity of delivery site	Positive
Ozimek JA et al. (2016)	US	Retrospective cohort	NGSG	SMM	Provider, patient, system factors	Provider factors is the majority of SMM	Positive
Kilpatrick SJ et al. (2016)	US	Retrospective cohort	CDC	SMM	Acute severe intrapartum hypertension	Acute severe intrapartum hypertension is higher risk of SMM	Positive
Martin AS et al. (2016)	US	Retrospective cohort	CDC	SMM	ART pregnancy	Singleton pregnancy with ART and any multiple birth are high risk of SMM	Positive

* CDC: Center for Disease. WHO: World Health Organization, Others include New Gold standard clinical guidelines.
† SMM: Severe maternal morbidity, SAMM: Severe acute maternal morbidity, MMR: Maternal mortality rate.

연세대학교
YONSEI UNIVERSITY

Table 2. Summary of previous literatures *(continued)*

Authors	Study population	Study Design	SMM criteria	Outcome variables	Interesting variables	Main finding	Relationship with SMM
Howell EA et al. (2016)	US	Cross-sectional	CDC	SMM	Black-serving hospital	High and middle black-serving hospitals had higher risk of SMM rate	Positive
Lindquist A et al. (2014)	Australia	Case-control	Others	SMM	Socioeconomic position	SMM is increased by disadvantaged area, maternal age, previous pregnancy complications, parity, cesarean delivery	Positive
Grobman WA et al. (2014)	US	Cohort study	Others	SMM	General factors	Women with older, cigarette used, medical aid, nulliparous, prior c-sec, comorbidities were higher risk of SMM	Positive
Creanga AA et al. (2013)	US	Cross-sectional	CDC	SMM	Racial and ethnic disparity	SMM is related to racial/ethnic minority women	Positive

* CDC: Center for Disease. WHO: World Health Organization, Others include New Gold standard clinical guidelines.
† SMM: Severe maternal morbidity, SAMM: Severe acute maternal morbidity, MMR: Maternal mortality rate.

연세대학교
YONSEI UNIVERSITY

Table 2. Summary of previous literatures *(continued)*

Authors	Study population	Study Design	SMM criteria	Outcome variables	Interesting variables	Main finding	Relationship with SMM
Callaghan WM et al. (2012)	US	Longitudinal	CDC	Postpartum readmission	SMM	SMM is increased the risk of postpartum readmission and overall mortality	Positive
Kayem G et al. (2011)	UK	National cohort study	Others	SMM, maternal death	General factors	Women with SMM, older, black ethnic, unemployed, obesity women were higher risk of maternal death.	Positive
Callaghan WM et al. (2007)	US	Cross-sectional	CDC	SMM	General factors	SMM is common at older age, black	Positive

* CDC: Center for Disease. WHO: World Health Organization, Others include New Gold standard clinical guidelines.
† SMM: Severe maternal morbidity, SAMM: Severe acute maternal morbidity, MMR: Maternal mortality rate.

연세대학교
YONSEI UNIVERSITY

Ⅲ. Materials and Methods

1. Conceptual framework

This study used two conceptual models. First, Donabedian's model with three key components of quality of care was applied to identify the relationship between SMM as outcome and other variables [89]. According to Donabedian's model, three types of quality of care are defined: structure, process, and outcome. In this study, structure is focused on accessibility using geographical accessibility. Process is defined as adequate prenatal care visits during pregnancy. Safety regarding severe maternal morbidity was considered another aspect of process and the first outcome. Lastly, outcome was defined in relation to effectiveness of postpartum readmission (Figure 2).

연세대학교
YONSEI UNIVERSITY

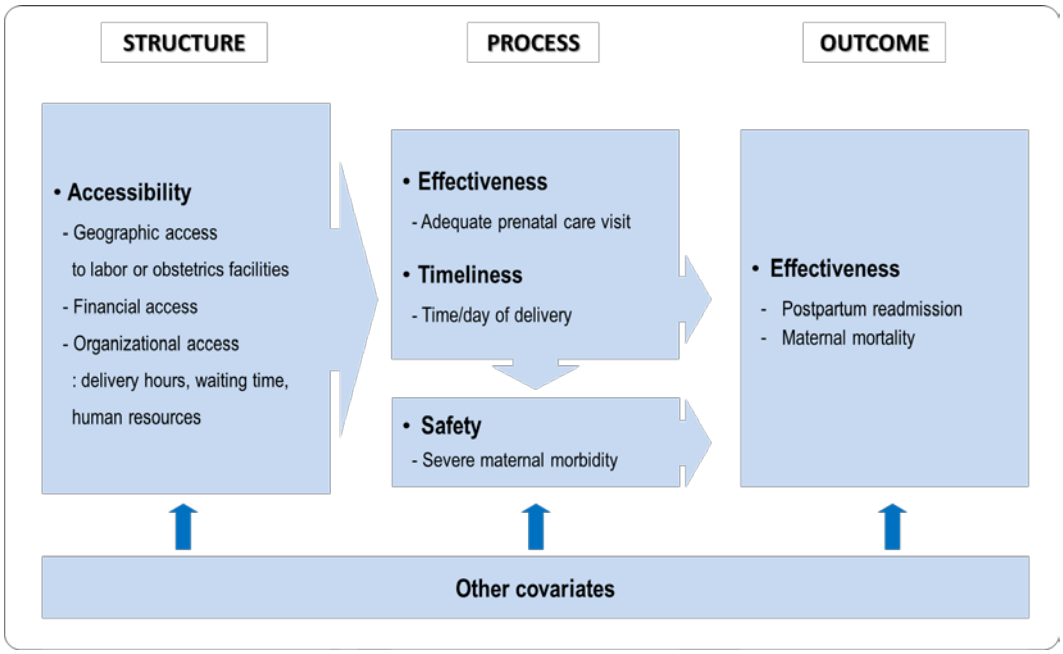

Figure 2. Conceptual framework for severe maternal morbidity and maternal health outcomes

Source: Austin A et al. Approaches to improve the quality of maternal and newborn health care: an overview of the evidence. Reproductive Health. 2014; 11(suppl 2): S1.

연세대학교
YONSEI UNIVERSITY

2. Data source and study population

The Korean National Health Insurance Service-National Sample Cohort (NHIS-NSC) is the national representative cohort database for the 2002-2013 period in South Korea, which includes information on approximately 1 million Koreans since 2002. The NHIS-NSC aims to track patient and clinical characteristics over time, reveal epidemiological causes of diseases, and develop health policies. The NHIS-NSC used a 2.5% (n = 1,025,340) stratified random sampling method, including age, sex, residence, health insurance type, family income decile, and individual total medical costs in 2002. Data do not contain direct personal identifiers but include the unique de-identified numbers of the patients, age, sex, type of insurance, diagnoses according to the International Classification of Diseases, 10th Revision (ICD-10), medical costs, procedures, and prescribed drugs. In addition, the unique de-identified numbers were linked to mortality information from the Korean National Statistical Office [90].

Furthermore, this study also used the Health Insurance Review and Assessment services (HIRA) claim data. The database included all health care resources for several obstetric hospitals/clinics, delivery facilities, and delivery rooms in each region, and region (unit of Si-Gun-Gu). We have merged this HIRA claim data to NHIS-NSC data to identify whether the region where a woman lived had obstetric resources [91].

Diagnosis and procedure codes were identified for all women aged 15 years or

연세대학교
YONSEI UNIVERSITY

older and less than 50 years old, who had a delivery hospitalization, and were continuously enrolled for at least 1 year before delivery through 42 days after delivery between January 1, 2003 and November 19, 2013. Deliveries were defined as any inpatient hospital admission records including a pregnancy-related diagnosis or procedure code for vaginal or cesarean delivery. Total selected participants were 91,767 women who delivered ether vaginally or by cesarean section delivery between 2003 and 2013 (Figure 3). The NHIS-NSC data included the exact childbirth date but did not include gestation commencement date; therefore, 266 days were subtracted from the day of childbirth to yield the first day of pregnancy.

연세대학교
YONSEI UNIVERSITY

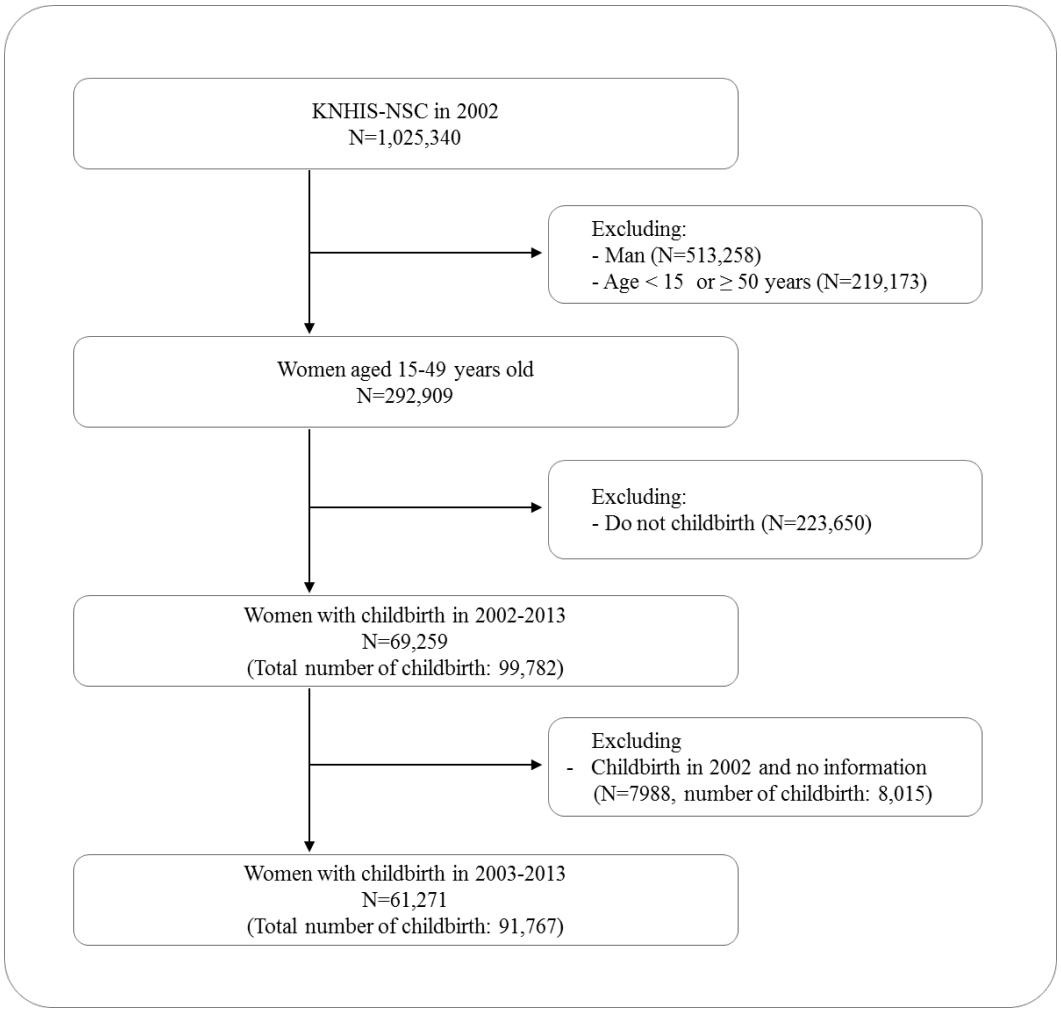

Figure 3. Flowchart for selecting participants

연세대학교
YONSEI UNIVERSITY

3. Construction of study variables

1) Dependent variables

This study has three dependent variables related to quality of maternal health care. The first dependent variable is severe maternal morbidity (SMM). SMM was identified by having at least 1 of the 25 previously established ICD-9-CM diagnosis and procedure codes (SMM indicators) during delivery hospitalizations using an algorithm developed by researchers at the Centers for Disease Control and Prevention (CDC) [21,22] (Appendix 1). The algorithm identified 25 indicators of severe maternal morbidity that represented either serious complications of pregnancy or delivery, such as eclampsia or acute renal failure, or procedures used to manage serious conditions, such as a blood transfusion. Of the 25 indicators, 18 were identified using diagnosis codes converted from ICD-9-CM to ICD-10, and seven indicators used procedure codes. A complete list of conditions and codes is available in Appendix 1. In addition, the delivery hospitalization had to meet at least one of the following two criteria to be considered SMM: 1) the mother was admitted in the ICU; or 2) the mother died during delivery hospitalization [38,42].

The second dependent variable is a postpartum readmission during the postpartum period. Postpartum readmission in this study was defined as a hospitalization that occurred within 42 days (6 weeks) after the date of delivery admission regardless of whether the same diagnosis had been given previously, and whether the diagnosis had

연세대학교
YONSEI UNIVERSITY

been recorded by obstetrics or not [45]. Readmission was defined with a patient episode involving a single admission if re-admission occurred within 2 days [92].

2) Independent variables

There are four independent variables as quality indicators: adequate prenatal care as effectiveness, access to labor or obstetric facilities as accessibility, day/time of delivery as timeliness, and severe maternal morbidity as safety.

(1) Effectiveness: adequate prenatal care

Adequate prenatal care was estimated by the Kessner Adequacy of Prenatal Care Index (KAPCI) [95]. To achieve an adequate KAPCI rating, one must start prenatal care in the first trimester and have nine prenatal care visits for a normal-length pregnancy [95]. This database did not have the date gestation began; therefore, in this study, the gestation date and the trimester period were evaluated. First, the gestation date was estimated to be 266 days before the day of delivery. The trimester period was divided so that the first trimester was from the gestation commencement date up to 14 weeks and 0 days of pregnancy, the second trimester was from 14 weeks and one day up to 28 weeks and 0 days, and the third trimester was from 28 weeks and one day up to the delivery date. Specific information about the KAPCI is included in Appendix 2.

(2) Accessibility: access to obstetric care

Access to obstetric care was defined as whether the woman's region of residence had a labor room and/or obstetric facilities or not. In this study, there were three categories: neither a labor room nor obstetric facilities; obstetric facilities present but no

연세대학교
YONSEI UNIVERSITY

labor room; and both a labor room and obstetric facilities present.

(3) Timeliness: day/time of delivery

Another quality of maternal care was measured using the day/time of delivery. The delivery of obstetric care changes dramatically depending on the time of the day or week [96-98]; therefore, day/time of delivery is associated with quality and safety of obstetric care [96]. This study identified four categories as follows: weekday and daytime delivery; weekday and nighttime delivery; weekend/holiday and daytime delivery; and weekend/holiday and nighttime delivery.

(4) Safety: severe maternal morbidity

Quality of maternal care was estimated using severe maternal morbidity indicators [22] on postpartum readmission and maternal mortality.

(5) Covariates

Individual factors such as maternal age (15-49 years old), household income level (quintile), residential area (metropolitan/city/rural), and type of insurance (self-employed insured/employee insured/medical aid), and working status (working/not working) were included as covariates in this analysis. The obstetric factors included mode of delivery (spontaneous vaginal delivery/instrumental delivery/cesarean section delivery), parity (1/2/3+), twin birth status (singleton/twin birth), preterm birth (yes/no), length of stay for delivery hospitalization (short-term/normal/long-term), comorbidities (yes/no). Hospital factors included type of hospital with regard to number of beds (clinic/hospital/general hospital), hospital ownership (government/private or for-profit),

연세대학교
YONSEI UNIVERSITY

hospital location (city/rural), hospital region (capital area//Gangwon region/Chungcheong region/Gyeongsang region/Jeolla region/Jeju region), and delivery year. The definitions of the variables are shown in Table 3.

연세대학교
YONSEI UNIVERSITY

Table 3. The definition of all variables

Variables	Definition
Outcome	
Severe maternal morbidity	CDC's algorism*
Postpartum readmission	Women who were unintended hospital readmission within 6 weeks postpartum period after delivery
Quality factors	
Adequate prenatal care	Using Kessner Adequacy of Prenatal Care Index †
Access to labor and/or obstetric facility	Women lives in area without labor and obstetric facility; 2) women lives in area with obstetric but without labor facility; 3) women lives in area with labor and obstetric facility
Time/day of delivery	1) Women delivered weekday and daytime; 2) women delivered weekday and nighttime; 3) women delivered weekend or holiday
Individual factors	
Maternal age	Age of delivery: 15-19; 20-24; 25-29; 30-34; 35-39; 40-44; 45-49
Household income	Quintile (0-2; 3-4; 5-6; 7-8; 9-10)
Type of insurance	Self-employed insured; employee insured; medical aid
Residential area	Using participants' zip code. Metropolitan (Seoul) ; City (other metropolitan cities); rural (others)
Obstetric factors	
Mode of delivery	Using EDI code. Spontaneous vaginal delivery; instrumental delivery (including by forceps and vacuum extractor, other assisted single delivery); cesarean section delivery
Parity	1; 2; 3+
Multiple birth	Singleton; twin or more than triplet
Preterm birth	≥ 37 weeks; < 37 weeks
Length of stay for delivery hospitalization	In vaginal and instrumental delivery, early (< 3 days); normal (= 3 days); late (> 3 days). In cesarean section delivery, early (< 6 days); normal (6-7 days); late (> 7 days). All cut-off points were determined by interquartile range (IQR)
Comorbidities during pregnancy‡	We used Howell's definition of comorbid conditions index [99]. We converted the ICD-9 code to the ICD-10 code.

* Appendix 1, † Appendix 2, ‡ Appendix 3

연세대학교
YONSEI UNIVERSITY

4. Statistical analysis

We calculated the distribution of the general characteristics of the study participants who delivered between 2003 and 2013. The characteristics of the severe maternal morbidity and non-severe maternal morbidity groups were compared using Pearson chi-square tests. Using a generalized estimating equation (GEE) model with logit link and a first order autoregressive correlation structure, we estimated adjusted odds ratios (ORs) and 95% confidence intervals (CIs) to examine which maternal characteristics were associated with severe maternal morbidity adjusted confounders. A GEE model with logit link was also performed for subgroups analysis by SMM and by adequate prenatal care. The relationship among severe maternal morbidity and postpartum hospital readmission were analyzed using time-to-event methods. Cumulative incidence curves were generated for comparison of unadjusted postpartum readmission rates according to the severe maternal morbidity status. To determine whether severe maternal morbidity was correlated with postpartum readmission, multivariate analyses were performed using Cox proportional hazards models with robust variance-covariance matrixes to account for repeated measures of individuals to calculate adjusted hazard ratios (HRs) and 95% CIs as an estimate of the relative rate of postpartum readmission. The proportionality assumption was tested by plotting Schoenfeld-like residuals. In addition, the relationship among severe maternal morbidity and maternal mortality during

연세대학교
YONSEI UNIVERSITY

the postpartum period and 1 year after delivery were analyzed with time-to-event methods. Cumulative incidence curves were used for comparison of unadjusted maternal mortality rates according to the severe maternal morbidity status. Cox proportional hazards models with robust variance-covariance matrixes to account for repeated measures of individuals were used to measure adjusted hazard ratios and 95% CIs as an estimate of the relative rate of maternal mortality. All statistical analyses were performed using SAS 9.4 (SAS Institute, Inc., Cary, NC, USA). The level of significance was set at $P<0.05$.

5. Ethics statements

This study adhered to the tenets of the Declaration of Helsinki, and the study design was reviewed and approved by the Yonsei University Health System, Institutional Review Board (Y-2017-0002).

연세대학교
YONSEI UNIVERSITY

Ⅳ. Results

1. General characteristics of the study population

Table 4 presents the general characteristics of the study participants according to SMM occurrence. Of the 91,767 women included in this study, 2,248 (2.45%) experienced SMM during the delivery hospitalization. In prenatal care, the proportion of SMM was higher in women who had intermediate prenatal care (2.77%) or inadequate prenatal care (4.02%) compared with adequate prenatal care (2.33%). In access to obstetric facilities, the proportion of SMM was lower in women who were living in an area with obstetric facilities and a labor room or who lived in an area with obstetric facilities only compared with those living without any obstetric or delivery facilities (2.43%, 2.63%, and 3.38%, respectively). Regarding time and day of delivery, the proportion of deliveries on weekends or holidays was the highest among those with SMM, followed by weekdays nighttime and weekdays daytime (3.57%, 2.82%, and 2.37%, respectively) (Table 4).

In the individual factors, the greatest proportions of SMM were higher among those who were teen aged, or 35 years old (15-19 years: 4.52%, 20-24: 2.40%, 25-29: 1.84%, 30-34: 2.31%, 35-39: 3.59%, 40-44: 6.24%, and more than 45 years: 10.45%, respectively), those with the lowest income level (2.91%), and those with medical aid (6.1%). For residential area, the proportion of SMM was similar for metropolitan areas,

연세대학교
YONSEI UNIVERSITY

cities, and rural areas (2.47%, 2.51%, and 2.41%, respectively). For working status, the proportion of SMM was similar for working or not working women (2.39% and 2.47%, respectively) (Table 4).

In obstetric factors, women with cesarean section delivery had a higher proportion of SMM, followed by instrumental delivery and spontaneous vaginal delivery (4.12%, 1.73%, and 1.24%, respectively). Regarding parity, nulliparous women had a higher proportion of SMM compared with second, and more than third births (2.76%, 1.80%, and 1.97%, respectively). For multiple birth status, twin or more than triplet births had a higher SMM rate (11.24%) compared with singleton birth (2.32%). Women who had a preterm birth prior to 37 weeks of gestation (9.62%) had a higher SMM rate compared with those who gave birth after 37 weeks (2.31%). Regarding length of stay for delivery hospitalization, long-term delivery hospitalization had the highest proportion of SMM, followed by short-term and normal (5.32%, 1.70%, and 1.43%, respectively). The proportion of SMM was higher among those who had comorbidities during pregnancy (22.04%), those who had intrapartum complications (5.57%), and postpartum complications (5.62%) compared with those who had neither comorbidities nor complications (Table 4).

In hospital factors, the proportion of SMM was highest in general hospitals with more than 500 beds, followed by general hospitals with less than 500 beds, hospitals with

연세대학교
YONSEI UNIVERSITY

100 to 500 beds, clinics with less than 30 beds, clinics with 30 to 100 beds, and hospitals with 30 to 100 beds (9.81%, 3.26%, 1.51%, 1.24%, 1.30%, and 1.41%, respectively). For hospital ownership, the proportion of SMM was higher in public hospitals (3.03%) than private or for-profit hospitals (2.45%). Hospitals in urban locations had a higher SMM rate (2.74%) compared with hospitals in rural locations (2.17%). The proportion of SMM was higher among those in the Gyeongsang region, followed by the Jeolla region, Chungcheong region, Capital area, Gangwon region, and Jeju region (2.81%, 2.72%, 2.51%, 2.25%, 1.90%, and 1.25%, respectively). In years, 2003 to 2005 had one of the highest proportions of SMM (in 2003: 2.74, in 2004: 2.91, and in 2005: 2.75%) (Table 4).

연세대학교
YONSEI UNIVERSITY

Table 4. General characteristics of the study population

	Severe maternal morbidity			
	Total (N = 91,767) **N(%)**	**No** (N = 89,519) **N(%)**	**Yes** (N = 2,248) **N(%)**	**P-value**
Adequacy of prenatal care				
Adequate	72801(79.33)	71102(97.67)	1699(2.33)	<.0001
Intermediate	17099(18.64)	16625(97.23)	474(2.77)	
Inadequate	1867(2.03)	1792(95.98)	75(4.02)	
Access to labor or obstetrics facility				
Both of None	1597(1.74)	1543(96.62)	54(3.38)	0.0466
Only obstetrics	1407(1.53)	1370(97.37)	37(2.63)	
Both	88763(96.73)	86606(97.57)	2157(2.43)	
Day/time of delivery				
Weekday daytime	80005(87.18)	78112(97.63)	1893(2.37)	<.0001
Weekday nighttime	8683(9.46)	8438(97.18)	245(2.82)	
Weekend or holiday	3079(3.36)	2969(96.43)	110(3.57)	
Individual factors				
Maternal age (years)				
15-19	310(0.34)	296(95.48)	14(4.52)	<.0001
20-24	4213(4.59)	4112(97.60)	101(2.40)	
25-29	28654(31.22)	28126(98.16)	528(1.84)	
30-34	43202(47.08)	42202(97.69)	1000(2.31)	
35-39	13526(14.75)	13040(96.41)	486(3.59)	
40-44	1795(1.96)	1683(93.76)	112(6.24)	
45-49	67(0.07)	60(89.55)	7(10.45)	
Income level				
1Q	8629(9.40)	8378(97.09)	251(2.91)	0.0361
2Q	13430(14.63)	13095(97.51)	335(2.49)	
3Q	24017(26.17)	23454(97.66)	563(2.34)	
4Q	29897(32.58)	29194(97.65)	703(2.35)	
5Q	15794(17.21)	15398(97.49)	396(2.51)	
Type of insurance				
Self-employed insured	26773(29.18)	26043(97.27)	730(2.73)	<.0001
Employee insured	64700(70.50)	63200(97.68)	1500(2.32)	
Medical aid	294(0.32)	276(93.90)	18(6.10)	
Residential area				
Metropolitan (Seoul)	18372(20.02)	17918(97.53)	454(2.47)	0.7089
City	23009(25.08)	22431(97.49)	578(2.51)	
Rural	50386(54.91)	49170(97.59)	1216(2.41)	
Working status				
Work	25524(27.81)	24913(97.61)	611(2.39)	0.4969
Not work	66243(72.19)	64606(97.53)	1637(2.47)	

연세대학교
YONSEI UNIVERSITY

Table 4. General characteristics of the study population *(continued)*

	Severe maternal morbidity			
	Total (N = 91,767) **N(%)**	**No** (N = 89,519) **N(%)**	**Yes** (N = 2,248) **N(%)**	**P-value**
Obstetric factors				
Mode of delivery				
Spontaneous vaginal delivery	32547(35.47)	32144(98.76)	403(1.24)	<.0001
Instrumental delivery	24917(27.15)	24487(98.27)	430(1.73)	
Cesarean section delivery	34303(37.38)	32888(95.88)	1415(4.12)	
Parity				
1 (Nulliparous)	61271(66.76)	59578(97.24)	1693(2.76)	<.0001
2	27046(29.47)	26559(98.20)	487(1.80)	
3+	3450(3.78)	3382(98.03)	68(1.97)	
Twin birth status				
Singleton	90441(98.56)	88342(97.68)	2099(2.32)	<.0001
Twin	1326(1.44)	1177(88.76)	149(11.24)	
Preterm birth				
≥ 37 weeks	90072(98.15)	87987(97.69)	2085(2.31)	<.0001
< 37 weeks	1695(1.85)	1532(90.38)	163(9.62)	
Length of stay for delivery hospitalization				
Short-term	6244(6.80)	6138(98.30)	106(1.70)	<.0001
Normal	61926(67.48)	61039(98.57)	887(1.43)	
Long-term	23597(25.71)	22342(94.68)	1255(5.32)	
Comorbidities during pregnancy				
0	90710(98.85)	88695(97.78)	2015(2.22)	<.0001
1+	1057(1.15)	824(77.96)	233(22.04)	
Hospital factors				
Type of hospital				
Clinic (<30 beds)	20461(22.30)	20172(98.59)	289(1.41)	<.0001
Clinic (30≤beds<100)	22227(24.22)	21938(98.70)	289(1.30)	
Hospital (30≤beds<100)	15932(17.36)	15734(98.76)	198(1.24)	
Hospital (100≤beds<500)	16592(18.08)	16341(98.49)	251(1.51)	
General hospital (<500 beds)	6159(6.71)	5958(96.74)	201(3.26)	
General hospital (≥500 beds)	10396(11.33)	9376(90.19)	1020(9.81)	
Hospital ownership				
Public	396(0.43)	384(96.97)	12(3.03)	0.4538
Private, for -profit	91371(99.57)	89135(97.55)	2236(2.45)	
Hospital location				
Urban	45524(49.61)	44278(97.26)	1246(2.74)	<.0001
Rural	46243(50.39)	45241(97.83)	1002(2.17)	

연세대학교
YONSEI UNIVERSITY

Table 4. General characteristics of the study population *(continued)*

	Severe maternal morbidity			
	Total (N = 91,767) **N(%)**	**No** (N = 89,519) **N(%)**	**Yes** (N = 2,248) **N(%)**	**P-value**
Hospital factors (continued)				
Hospital region				
Capital area	45595(49.69)	44568(97.75)	1027(2.25)	<.0001
Gangwon region	2265(2.47)	2222(98.10)	43(1.90)	
Chungcheong region	9234(10.06)	9002(97.49)	232(2.51)	
Gyeongsang region	23469(25.57)	22810(97.19)	659(2.81)	
Jeolla region	10006(10.91)	9734(97.28)	272(2.72)	
Jeju region	1198(1.31)	1183(98.75)	15(1.25)	
Year				
2003	8526(9.29)	8292(97.26)	234(2.74)	0.0012
2004	8475(9.23)	8229(97.10)	246(2.90)	
2005	8193(8.93)	7968(97.25)	225(2.75)	
2006	8217(8.95)	8022(97.63)	195(2.37)	
2007	9019(9.83)	8789(97.45)	230(2.55)	
2008	8281(9.02)	8112(97.96)	169(2.04)	
2009	7570(8.25)	7384(97.54)	186(2.46)	
2010	7970(8.69)	7765(97.43)	205(2.57)	
2011	8653(9.43)	8467(97.85)	186(2.15)	
2012	8871(9.67)	8664(97.67)	207(2.33)	
2013	7992(8.71)	7827(97.94)	165(2.06)	

Table 5 shows the distribution of SMM indicators. Most deliveries with SMM (86%) had one indicator (out of a total of 25 SMM indicators), 9% of deliveries had two indicators, and 5% had three or more indicators present (Table 5). Table 6 presents the frequency of SMM divided by diagnosis-based indicators and procedure-based indicators. The most frequent SMM indicator was blood transfusion (1670 cases, 59.7% of total cases), followed by disseminated intravascular coagulation (252 cases, 9.0%), ICU (160 cases, 5.7%), shock (138 cases, 4.9%), hysterectomy (102 cases, 3.6%), eclampsia (96 cases, 3.4%), pulmonary edema (85 cases, 3.0%), ventilation (54 cases, 1.9%), and others

연세대학교
YONSEI UNIVERSITY

(Table 6). The leading diagnosis-based indicators of SMM were complications of disseminated intravascular coagulation (31.7% of diagnosis-based indicators), shock (17.4%), sepsis (12.7%), eclampsia (12.1%), pulmonary edema (10.7%), adult respiratory distress syndrome (2.9%), severe anesthesia complications (2.9%), thrombotic embolism (2.9%), and others (6.8%) (Table 6). The leading procedure-based indicators included blood transfusion (90.6% of procedure-based indicators), hysterectomy (5.5%), ventilation (2.9%), and others (Table 6).

Table 5. Distribution of severe maternal morbidity indicators

Number of SMM	%	N
1 indicator	86%	1924
2 indicators	9%	213
3 or more indicators	5%	111
Total	100%	2248

연세대학교
YONSEI UNIVERSITY

Table 6. Number of cases and proportion on severe maternal morbidity indicators

	N	%	%*
Diagnosis-based indicators			
Disseminated intravascular coagulation	252	9.0	31.7
Shock	138	4.9	17.4
Sepsis	101	3.6	12.7
Eclampsia	96	3.4	12.1
Pulmonary edema	85	3.0	10.7
Adult respiratory distress syndrome	23	0.8	2.9
Complications during procedure or surgery	23	0.8	2.9
Thrombotic embolism	23	0.8	2.9
Internal injuries of thorax, abdomen, and pelvis	16	0.6	2.0
Puerperal cerebrovascular disorders	15	0.5	1.9
Acute myocardial infarction	14	0.5	1.8
Amniotic fluid embolism	5	0.2	0.6
Cardiac arrest	3	0.1	0.4
Aneurysm	1	0.0	0.1
Intracranial injuries	0	0.0	0.0
Acute renal failure	0	0.0	0.0
Heart failure	0	0.0	0.0
Sickle cell anemia with crisis	0	0.0	0.0
Procedure-based indicators			
Blood transfusion	1670	59.7	90.6
Hysterectomy	102	3.6	5.5
Ventilation	54	1.9	2.9
Cardio monitoring	9	0.3	0.5
Conversion of cardiac rhythm	6	0.2	0.3
Temporary tracheostomy	2	0.1	0.1
Operations on the heart and pericardium	0	0.0	0.0
ICU	160	5.7	
SMM overall	**2798**		

연세대학교
YONSEI UNIVERSITY

2. Effects of severe maternal morbidity and risk factors

Table 7 presents the association between SMM and maternity risk factors adjusted for all covariates. Women who had inadequate prenatal care had significantly higher odds of SMM compared with those who had adequate prenatal care (OR 1.39, 95% CI 1.08-1.79). In access to labor or obstetric facilities, women who lived without either labor or obstetric facilities had higher odds of SMM, but there was no significant association (OR 0.96, 95% CI 0.85-1.08). For day and time of delivery, women who delivered on a weekend or holiday and on weekday nighttime had significantly higher odds compared with those who delivered on weekday daytime (weekend: OR 1.70, 95% CI 1.17-1.84; and weekday nighttime: OR 1.18, 95% CI 1.02-1.38).

Women's sociodemographic factors were significantly associated with SMM, as shown in Table 7. Age was significantly associated with SMM in all age categories. Women who were 45 and older had the highest odds of SMM (OR 3.28, 95% CI 1.41-7.63), adolescents who were 15 to 19 years old had the second highest odds (OR 2.13, 95% CI 1.22-3.74), women aged 40 to 44 and 35 to 39 had higher odds (OR 2.06, 95% CI 1.63-2.61; and OR 1.45, 95% CI 1.27-1.66, respectively), and women aged 20 to 24 and 30 to 34 years old had higher odds (OR 1.29, 95% CI 1.04-1.62; and OR 1.18, 95% CI 1.06-1.32, respectively) compared with those aged 25 to 29 years old. For type of insurance, self-employed insured and medical aid women had higher odds compared with

연세대학교
YONSEI UNIVERSITY

those were employee insured, but there was no significant association.

Obstetric factors were significantly associated with SMM (Table 7). In mode of delivery, cesarean section delivery had significantly higher odds of SMM compared with spontaneous vaginal delivery (OR 2.48, 95% CI 2.20-2.79). In parity, nulliparous women had higher odds of SMM (OR 1.21, 95% CI 1.08-1.36), however, there was no significant association between women who had more than three delivery times and SMM adjusted for all covariates. Multiple births (twins, triplets or more) had significantly higher odds of SMM compared with those had singleton births (OR 1.82, 95% CI 1.47-2.24). Preterm birth before 37 weeks of gestation had slightly higher odds than childbirth after 37 weeks of gestation (OR 1.01, 95% CI 0.83-1.23). For the length of stay for delivery hospitalization, women who had long-term delivery hospitalization had significantly higher odds of SMM compared with those who were discharged normally (OR 3.00, 95% CI 2.73-3.29). Women who had comorbidities during pregnancy had significantly higher odds compared with those who did not have them (OR 7.81, 95% CI 6.57-9.29).

Hospital factors were related to SMM, as shown in Table 7. General hospitals with more than 500 beds had the highest odds of SMM (OR 6.36, 95% CI 5.40-7.49), general hospitals with less than 500 beds had 2.2 times higher odds of SMM (OR 2.19, 95% CI 1.77-2.71), hospitals with 30 to 100 beds and clinics with less than 30 beds had higher odds compared with hospitals with 30 to 100 beds (OR 1.23, 95% CI 1.01-1.49; and OR

연세대학교
YONSEI UNIVERSITY

1.34, 95% CI 1.11-1.63, respectively). For-profit hospitals had higher odds of SMM than public hospitals (OR 2.20, 95% CI 1.20-4.03). For hospital region, the Jeolla region had 1.3 times higher odds of SMM (OR 1.30, 95% CI 1.12-1.52), while Gangwon and the Jeju region had significantly lower odds compared with the Capital area (OR 0.64, 95% CI 0.45-0.89; and OR 0.47, 95% CI 0.27-0.83, respectively).

연세대학교
YONSEI UNIVERSITY

Table 7. The relationship between severe maternal morbidity and risk factors

	Severe maternal morbidity			
	OR	**95% CI**		**P-value**
Adequacy of prenatal care				
Adequate	1.00			
Intermediate	0.96	0.85	1.08	0.5309
Inadequate	1.39	1.08	1.79	0.0107
Access to labor or obstetrics facility				
Both of None	1.22	0.90	1.64	0.2009
Only obstetrics	1.08	0.76	1.53	0.6855
Both	1.00			
Day/time of delivery				
Weekday daytime	1.00			
Weekday nighttime	1.18	1.02	1.38	0.0302
Weekend or holiday	1.70	1.37	2.11	<.0001
Individual factors				
Maternal age (years)				
15-19	2.13	1.22	3.74	0.0082
20-24	1.29	1.04	1.62	0.0234
25-29	1.00			
30-34	1.18	1.06	1.32	0.0033
35-39	1.45	1.27	1.66	<.0001
40-44	2.06	1.62	2.61	<.0001
45-49	3.28	1.41	7.63	0.0058
Income level				
1Q	1.25	1.04	1.49	0.0146
2Q	1.14	0.97	1.34	0.1106
3Q	1.09	0.95	1.25	0.2324
4Q	1.05	0.92	1.20	0.4742
5Q	1.00			
Type of insurance				
Self-employed insured	1.09	0.99	1.20	0.0922
Employee insured	1.00			
Medical aid	1.54	0.89	2.64	0.1205
Residential area				
Metropolitan (Seoul)	1.00			
City	1.03	0.88	1.21	0.6965
Rural	1.12	0.96	1.30	0.1544
Working status				
Work	1.00			
Not work	1.09	0.99	1.21	0.0832

연세대학교
YONSEI UNIVERSITY

Table 7. The relationship between severe maternal morbidity and risk factors *(continued)*

	Severe maternal morbidity			
	OR	**95% CI**		**P-value**
Obstetric factors				
Mode of delivery				
Spontaneous vaginal delivery	1.00			
Instrumental delivery	1.03	0.90	1.19	0.6551
Cesarean section delivery	2.48	2.20	2.79	<.0001
Parity				
1 (Nulliparous)	1.21	1.08	1.36	0.0007
2	1.00			
3+	1.04	0.80	1.35	0.7632
Twin birth status				
Singleton	1.00			
Twin	1.82	1.47	2.24	<.0001
Preterm birth				
≥ 37 weeks	1.00			
< 37 weeks	1.01	0.83	1.23	0.9384
Length of stay for delivery hospitalization				
Short-term	0.84	0.69	1.04	0.1069
Normal	1.00			
Long-term	3.00	2.73	3.29	<.0001
Comorbidities during pregnancy				
0	1.00			
1+	7.81	6.57	9.29	<.0001
Hospital factors				
Type of hospital				
Clinic (<30 beds)	1.34	1.11	1.63	0.0025
Clinic (30≤beds<100)	1.16	0.96	1.40	0.1341
Hospital (30≤beds<100)	1.00			
Hospital (100≤beds<500)	1.23	1.01	1.49	0.0387
General hospital (<500 beds)	2.19	1.77	2.71	<.0001
General hospital (≥500 beds)	6.36	5.40	7.49	<.0001
Hospital ownership				
Public	1.00			
Private, for -profit	2.20	1.20	4.03	0.0107
Hospital location				
Urban	1.00			
Rural	0.96	0.84	1.09	0.5556
Hospital region				
Capital area	1.00			
Gangwon region	0.64	0.45	0.89	0.0091
Chungcheong region	1.12	0.95	1.32	0.1930
Gyeongsang region	1.12	0.99	1.27	0.0689
Jeolla region	1.30	1.12	1.52	0.0007
Jeju region	0.47	0.27	0.83	0.0083

연세대학교
YONSEI UNIVERSITY

Table 7. The relationship between severe maternal morbidity and risk factors *(continued)*

	Severe maternal morbidity			
	OR	**95% CI**		**P-value**
Year				
2003	1.00			
2004	1.16	0.96	1.40	0.1354
2005	1.10	0.90	1.34	0.3491
2006	1.02	0.83	1.25	0.8580
2007	1.08	0.89	1.33	0.4308
2008	0.83	0.67	1.04	0.1067
2009	1.11	0.90	1.38	0.3349
2010	1.09	0.88	1.35	0.4311
2011	0.88	0.70	1.11	0.2817
2012	0.93	0.75	1.16	0.5286
2013	0.85	0.67	1.08	0.1826

OR: odds ratio

연세대학교
YONSEI UNIVERSITY

3. Subgroup analysis for severe maternal morbidity

1) Subgroup analysis by outcome variable

(1) Subgroup analysis by diagnosis-based SMM

Table 8 shows the relationship between quality indicators, childbirth age, and obstetric factors, and the most frequent indicators in diagnosis- and procedure-based SMM. For disseminated intravascular coagulation, women who had cesarean section delivery (OR 1.99, 95% CI 1.34-2.94), and who had long-term delivery hospitalization (OR 3.84, 95% CI 2.75-5.31) had significantly higher odds adjusted for all covariates (Table 8). Shock was significantly associated with inadequate prenatal care (OR 2.82, 95% CI 1.09-7.33). Additionally, women who had cesarean section delivery, and who had long-term delivery hospitalization had higher odds of shock (OR 2.10, 95% CI 1.33-3.31; and OR 2.08, 95% CI 1.46-2.97, respectively) (Table 8). Sepsis had higher odds related to inaccessibility to labor facilities, being aged 40 to 44, and long-term delivery hospitalization (OR 4.06 95% CI 1.51-10.88; OR 3.62, 95% CI 1.45-9.00; and OR 5.09, 95% CI 3.27-7.93, respectively) (Table 8). Regarding eclampsia, women who had cesarean section delivery (OR 2.40, 95% CI 1.50-3.83), who were nulliparous (OR 2.90, 95% CI 1.37-6.16), or who had long-term delivery hospitalization (OR 3.84, 95% CI 2.75-5.31) had significantly higher odds adjusted for all covariates (Table 8).

연세대학교
YONSEI UNIVERSITY

(2) Subgroup analysis by procedure-based SMM

Table 9 shows the relationship between quality, individual, and obstetric factors, and the most frequent indicators in procedure-based SMM adjusted for all covariates. Blood transfusion was associated with the most frequent occurrence of SMM, and was related to several quality, maternal age, and obstetric factors. Inadequate prenatal care was 1.55 times higher odds compared with adequate prenatal care (OR 1.55, 95% CI 1.17-2.05), and weekday nighttime and weekend or holiday delivery had higher odds compared with weekday daytime delivery (OR 1.26, 95% CI 1.06-1.50; and OR 1.68, 95% CI 1.31-2.15, respectively). Maternal age was significantly related to blood transfusion, especially in women who were adolescents or aged 45 or more; the odds of blood transfusion showed a J-shaped pattern across age groups (15-19 years: OR 3.02, 95% CI 1.72-5.32; 20-24 years: OR 1.43, 95% CI 1.11-1.84; 30-34 years OR 1.29, 95% CI 1.13-1.47; 35-39 years: OR 1.61, 95% CI 1.38-1.88; 40-44 years: OR 2.28, 95% CI 1.75-2.97; and 45-49 years: OR 4.02, 95% CI 1.68-9.66, respectively). Furthermore, women who had cesarean section delivery (OR 2.53, 95% CI 2.20-2.91), who were nulliparous (OR 1.24, 95% CI 1.09-1.41), who had multiple births (OR 1.89, 95% CI 1.50-2.39), or who had long-term delivery hospitalization (OR 2.85, 95% CI 2.55-3.17) had higher odds of blood transfusion. Hysterectomy was significantly related to women being aged 35 or more (35-39 years: OR 1.98, 95% CI 1.06-3.70; and 40-44 years: OR 14.03, 95% CI

연세대학교
YONSEI UNIVERSITY

1.69-9.62), instrumental and cesarean section delivery (OR 3.30, 95% CI 1.09-9.99; and OR 12.16, 95% CI 4.30-34.35, respectively), twin birth (OR 2.64, 95% CI 1.17-5.99), and long-term delivery hospitalization (OR 11.13, 95% CI 6.53-18.98). As shown in Table 10, women who had inadequate prenatal care (OR 2.35, 95% CI 1.09-5.08), were aged 40-44 years (OR 3.04, 95% CI 1.56-5.92), who had cesarean section delivery (OR 2.73, 95% CI 1.68-4.46), and long-term delivery hospitalization (OR 6.32, 95% CI 4.10-9.76) had the highest odds of ICU.

연세대학교
YONSEI UNIVERSITY

Table 8. The result of subgroup analysis for diagnosis-based SMM

	Diagnosis-based SMM							
	DIC				Shock			
	OR	95% CI		P-value	OR	95% CI		P-value
Adequacy of prenatal care								
Adequate	1.00				1.00			
Intermediate	0.88	0.56	1.38	0.5725	0.75	0.41	1.40	0.3711
Inadequate	1.52	0.74	3.13	0.2575	2.82	1.09	7.33	0.0329
Access to labor or obstetrics facility								
Both of None	1.76	0.55	5.62	0.3377	1.89	0.81	4.40	0.1416
Only obstetrics	1.06	0.34	3.27	0.9188	1.07	0.32	3.62	0.9151
Both	1.00				1.00			
Day/time of delivery								
Weekday daytime	1.00				1.00			
Weekday nighttime	0.87	0.53	1.43	0.5876	1.35	0.79	2.31	0.2790
Weekend or holiday	1.77	0.93	3.35	0.0800	1.58	0.75	3.34	0.2270
Maternal age (years)								
15-19	0.69	0.02	23.91	0.8352	-			
20-24	1.57	0.68	3.62	0.2946	0.62	0.18	2.18	0.4588
25-29	1.00				1.00			
30-34	1.09	0.74	1.61	0.6637	1.59	0.99	2.56	0.0569
35-39	0.97	0.61	1.54	0.9015	1.69	0.97	2.94	0.0637
40-44	0.73	0.33	1.59	0.4223	1.34	0.53	3.40	0.5396
45-49	3.28	0.89	12.07	0.0739	-			
Mode of delivery								
Spontaneous vaginal delivery	1.00				1.00			
Instrumental delivery	1.55	0.98	2.44	0.0585	0.74	0.40	1.36	0.3303
Cesarean section delivery	1.99	1.34	2.94	0.0006	2.10	1.33	3.31	0.0014
Parity								
1 (Nulliparous)	1.22	0.83	1.79	0.3174	1.31	0.88	1.95	0.1763
2	1.00				1.00			
3+	1.97	0.76	5.11	0.1644	0.55	0.20	1.56	0.2650
Twin birth status								
Singleton	1.00				1.00			
Twin	0.99	0.48	2.03	0.9829	0.70	0.25	1.96	0.5021
Preterm birth								
≥ 37 weeks	1.00				1.00			
< 37 weeks	0.42	0.23	0.76	0.0044	0.24	0.07	0.83	0.0244
Length of stay for delivery hospitalization								
Short-term	1.19	0.54	2.65	0.6683	0.74	0.31	1.77	0.4994
Normal	1.00				1.00			
Long-term	3.82	2.75	5.31	<.0001	2.08	1.46	2.97	<.0001
Comorbidities during pregnancy								
0	1.00				1.00			
1+	219.40	156.33	307.94	<.0001	16.60	9.66	28.51	<.0001

SMM: Severe maternal morbidity, DIC: Disseminated intravascular coagulation
* Adjusted for all covariates

연세대학교
YONSEI UNIVERSITY

Table 8. The result of subgroup analysis for diagnosis-based SMM *(continued)*

	Diagnosis-based SMM							
	Sepsis				Eclampsia			
	OR	95% CI		P-value	OR	95% CI		P-value
Adequacy of prenatal care								
Adequate	1.00				1.00			
Intermediate	0.82	0.49	1.36	0.4340	0.70	0.44	1.13	0.1439
Inadequate	0.72	0.17	3.05	0.6571	0.39	0.10	1.53	0.1746
Access to labor or obstetrics facility								
Both of None	1.77	0.52	6.02	0.3622	1.56	0.62	3.93	0.3494
Only obstetrics	4.06	1.51	10.88	0.0054	2.36	0.80	6.94	0.1178
Both	1.00				1.00			
Day/time of delivery								
Weekday daytime	1.00				1.00			
Weekday nighttime	1.41	0.72	2.76	0.3137	1.35	0.57	3.19	0.5002
Weekend or holiday	1.94	0.74	5.07	0.1752	1.72	0.55	5.45	0.3539
Maternal age (years)								
15-19	-				-			
20-24	1.23	0.46	3.28	0.6803	0.85	0.33	2.19	0.7290
25-29	1.00				1.00			
30-34	0.96	0.58	1.59	0.8793	1.06	0.68	1.65	0.7906
35-39	1.42	0.77	2.64	0.2652	0.86	0.42	1.76	0.6725
40-44	3.62	1.45	9.00	0.0057	2.31	0.67	7.97	0.1849
45-49	-				-			
Mode of delivery								
Spontaneous vaginal delivery	1.00				1.00			
Instrumental delivery	0.78	0.46	1.33	0.3622	1.05	0.60	1.86	0.8550
Cesarean section delivery	1.00	0.62	1.61	0.9982	2.40	1.50	3.83	0.0002
Parity								
1 (Nulliparous)	0.86	0.54	1.38	0.5337	2.90	1.37	6.16	0.0054
2	1.00				1.00			
3+	1.07	0.31	3.72	0.9161	2.73	0.32	23.13	0.3581
Twin birth status								
Singleton	1.00				1.00			
Twin	0.83	0.20	3.38	0.7904	1.62	0.60	4.34	0.3407
Preterm birth								
≥ 37 weeks	1.00				1.00			
< 37 weeks	0.39	0.09	1.69	0.2060	-			
Length of stay for delivery hospitalization								
Short-term	1.90	0.77	4.71	0.1661	0.28	0.04	2.07	0.2121
Normal	1.00				1.00			
Long-term	5.09	3.27	7.93	<.0001	2.61	1.69	4.04	<.0001
Comorbidities during pregnancy								
0	1.00				1.00			
1+	6.67	3.46	12.87	<.0001	3.71	1.10	12.52	0.0345

SMM: Severe maternal morbidity
* Adjusted for all covariates

연세대학교
YONSEI UNIVERSITY

Table 9. The result of subgroup analysis for procedure-based SMM

	Procedure-based SMM					
	Blood transfusion			Hysterectomy		
	OR	95% CI	P-value	OR	95% CI	P-value
Adequacy of prenatal care						
Adequate	1.00			1.00		
Intermediate	1.02	0.891.17	0.7828	1.15	0.71 1.87	0.5666
Inadequate	1.55	1.172.05	0.0022	1.30	0.44 3.82	0.6302
Access to labor or obstetrics facility						
Both of None	1.02	0.711.46	0.9254	2.26	0.76 6.74	0.1431
Only obstetrics	0.94	0.621.43	0.7674	0.81	0.12 5.64	0.8301
Both	1.00			1.00		
Day/time of delivery						
Weekday daytime	1.00			1.00		
Weekday nighttime	1.26	1.061.50	0.0079	0.08	0.01 0.57	0.0120
Weekend or holiday	1.68	1.312.15	<.0001	-		
Maternal age (years)						
15-19	3.02	1.725.32	0.0001	-		
20-24	1.43	1.111.84	0.0060	0.60	0.14 2.57	0.4873
25-29	1.00			1.00		
30-34	1.29	1.131.47	0.0002	1.46	0.83 2.56	0.1866
35-39	1.61	1.381.88	<.0001	1.98	1.06 3.70	0.0316
40-44	2.28	1.752.97	<.0001	4.03	1.69 9.62	0.0017
45-49	4.02	1.689.66	0.0018	-		
Mode of delivery						
Spontaneous vaginal delivery	1.00			1.00		
Instrumental delivery	1.18	1.001.39	0.0504	3.30	1.09 9.99	0.0344
Cesarean section delivery	2.53	2.202.91	<.0001	12.16	4.3034.35	<.0001
Parity						
1 (Nulliparous)	1.24	1.091.41	0.0011	0.73	0.44 1.19	0.2093
2	1.00			1.00		
3+	0.95	0.701.29	0.7397	0.30	0.04 2.24	0.2419
Twin birth status						
Singleton	1.00			1.00		
Twin	1.89	1.502.39	<.0001	2.64	1.17 5.99	0.0197
Preterm birth						
≥ 37 weeks	1.00			1.00		
< 37 weeks	1.00	0.801.25	0.9982	0.28	0.06 1.20	0.0866
Length of stay for delivery hospitalization						
Short-term	0.92	0.741.16	0.4879	0.39	0.05 2.94	0.3586
Normal	1.00			1.00		
Long-term	2.85	2.553.17	<.0001	11.13	6.5318.98	<.0001
Comorbidities during pregnancy						
0	1.00			1.00		
1+	4.17	3.345.20	<.0001	4.52	2.09 9.77	0.0001

* Adjusted for all covariates; SMM: Severe maternal morbidity

연세대학교
YONSEI UNIVERSITY

Table 10. The result of subgroup analysis for ICU among SMM

	SMM			
	ICU			
	OR	**95% CI**		**P-value**
Adequacy of prenatal care				
Adequate	1.00			
Intermediate	1.19	0.79	1.81	0.4048
Inadequate	2.35	1.09	5.08	0.0293
Access to labor or obstetrics facility				
Both of None	1.98	0.64	6.14	0.2393
Only obstetrics	0.63	0.08	4.94	0.6574
Both	1.00			
Day/time of delivery				
Weekday daytime	1.00			
Weekday nighttime	1.12	0.65	1.95	0.6864
Weekend or holiday	1.45	0.66	3.18	0.3598
Maternal age (years)				
15-19				
20-24	0.79	0.27	2.30	0.6606
25-29	1.00			
30-34	1.24	0.79	1.94	0.3460
35-39	1.56	0.93	2.60	0.0894
40-44	3.04	1.56	5.92	0.0011
45-49				
Mode of delivery				
Spontaneous vaginal delivery	1.00			
Instrumental delivery	1.17	0.67	2.05	0.5784
Cesarean section delivery	2.73	1.68	4.46	<.0001
Parity				
1 (Nulliparous)	1.15	0.75	1.75	0.5218
2	1.00			
3+	1.42	0.55	3.70	0.4668
Twin birth status				
Singleton	1.00			
Twin	0.84	0.39	1.81	0.6598
Preterm birth				
≥ 37 weeks	1.00			
< 37 weeks	0.70	0.38	1.30	0.2623
Length of stay for delivery hospitalization				
Short-term	1.84	0.86	3.97	0.1175
Normal	1.00			
Long-term	6.32	4.10	9.76	<.0001
Comorbidities during pregnancy				
0	1.00			
1+	11.44	7.33	17.84	<.0001

* Adjusted for all covariates; SMM: Severe maternal morbidity; ICU: Intensive care unit

연세대학교
YONSEI UNIVERSITY

2) Subgroup analysis by independent variables

Table 11 presents the subgroup analysis by independent variables. By access to labor or obstetric facilities, women who lived in regions without access to labor and obstetrics facilities and who had inadequate prenatal care had higher odds of SMM, although this was not a significant association. Women who lived in regions with access to both labor and obstetrics facilities and who had inadequate prenatal care also had 1.3 times high odds of SMM.

Regarding day/time of delivery, women who delivered on weekday nighttime and who had inadequate prenatal care had significantly higher odds of SMM (OR 4.13, 95% CI 1.79-9.53). Weekday daytime delivery and inadequate prenatal care were associated with higher odds of SMM, but the association was not significant. Additionally, there was no association between weekend or holiday delivery and inadequate prenatal care for SMM.

By maternal age, women aged 20-24 years and 30-34 years, and who had inadequate prenatal care had significantly higher odds of SMM (OR 3.29, 95% CI 1.71-6.33; and OR 1.71 95% CI 1.14-2.57, respectively). By mode of delivery, women who had spontaneous vaginal delivery and cesarean section delivery, and who had inadequate prenatal care had significantly higher odds of SMM (OR 1.94, 95% CI 1.21-3.11; and OR 1.46, 95% CI 1.05-2.03, respectively). By parity, nulliparous women with inadequate prenatal care had 1.4 times higher odds compared with those with adequate prenatal care of SMM (OR 1.42, 95% CI 1.08-1.87). Women who had delivered two or more times,

연세대학교
YONSEI UNIVERSITY

and who had inadequate prenatal care had higher odds of SMM although the association was not significant. By twin birth status, women with singleton birth and inadequate prenatal care had higher odds of SMM (OR 1.38, 95% CI 1.06-1.79), while for twin birth women with inadequate prenatal care, the association was not significant. By preterm birth, women who delivered after 37 weeks with inadequate prenatal care had significantly higher odds of SMM (OR 1.44, 95% CI 1.10-1.88). However, for preterm birth women with inadequate prenatal care, the association was not significant (OR 2.09, 95% CI 0.77-5.66).

연세대학교
YONSEI UNIVERSITY

Table 11. Result of subgroup analysis by independent variables

			Severe maternal morbidity			
			OR	95% CI		P-value
Access to labor or obstetrics facility		Adequate prenatal care				
	Both of None	Adequate	1.00			
		Intermediate	0.69	0.28	1.73	0.4304
		Inadequate	2.28	0.49	10.56	0.2918
	Only obstetrics	Adequate	-	-	-	
		Intermediate	-	-	-	
		Inadequate	-	-	-	
	Both	Adequate	1.00			
		Intermediate	0.96	0.85	1.08	0.5124
		Inadequate	1.30	1.01	1.68	0.0419
Day/time of delivery		Adequate prenatal care				
	Weekday daytime	Adequate	1.00			
		Intermediate	0.93	0.82	1.06	0.2659
		Inadequate	1.29	0.98	1.68	0.0692
	Weekday nighttime	Adequate	1.00			
		Intermediate	1.00	0.67	1.50	0.9957
		Inadequate	4.13	1.79	9.53	0.0009
	Weekend or holiday	Adequate	1.00			
		Intermediate	1.66	0.90	3.04	0.1042
		Inadequate	0.35	0.03	4.13	0.4080
Maternal age (years)		Adequate prenatal care				
	15-19	Adequate	-	-	-	
		Intermediate	-	-	-	
		Inadequate	-	-	-	
	20-24	Adequate	1.00			
		Intermediate	2.26	1.34	3.83	0.0024
		Inadequate	3.29	1.71	6.33	0.0004
	25-29	Adequate	1.00			
		Intermediate	0.76	0.59	0.97	0.0294
		Inadequate	0.96	0.55	1.67	0.8723
	30-34	Adequate	1.00			
		Intermediate	1.03	0.86	1.23	0.7737
		Inadequate	1.71	1.14	2.57	0.0089
	35-39	Adequate	1.00			
		Intermediate	0.89	0.69	1.15	0.3762
		Inadequate	0.66	0.31	1.40	0.2763
	40-44	Adequate	1.00			
		Intermediate	0.77	0.45	1.33	0.3497
		Inadequate	1.09	0.38	3.11	0.8678
	45-49	Adequate	-	-	-	
		Intermediate	-	-	-	
		Inadequate	-	-	-	

* Adjusted for all covariates.

연세대학교
YONSEI UNIVERSITY

Table 11. Result of subgroup analysis by independent variables *(continued)*

			Severe maternal morbidity			
			OR	**95% CI**		**P-value**
Mode of delivery		Adequate prenatal care				
	Spontaneous vaginal delivery	Adequate	1.00			
		Intermediate	0.95	0.73	1.24	0.7248
		Inadequate	1.94	1.21	3.11	0.0057
	Instrumental delivery	Adequate	1.00			
		Intermediate	0.73	0.54	0.99	0.0420
		Inadequate	0.66	0.26	1.62	0.3599
	Cesarean section delivery	Adequate	1.00			
		Intermediate	1.05	0.90	1.22	0.5577
		Inadequate	1.46	1.05	2.03	0.0256
Parity		Adequate prenatal care				
	1 (Nulliparous)	Adequate	1.00			
		Intermediate	1.01	0.88	1.15	0.9145
		Inadequate	1.42	1.08	1.87	0.0118
	2	Adequate	1.00			
		Intermediate	0.85	0.66	1.11	0.2282
		Inadequate	1.45	0.71	2.93	0.3054
	3+ *	Adequate	1.00			
		Intermediate	0.73	0.35	1.55	0.4129
		Inadequate	1.17	0.26	5.29	0.8424
Twin birth status		Adequate prenatal care				
	Singleton	Adequate	1.00			
		Intermediate	0.97	0.86	1.10	0.6185
		Inadequate	1.38	1.06	1.79	0.0164
	Twin	Adequate	1.00			
		Intermediate	0.76	0.42	1.39	0.3797
		Inadequate	1.40	0.44	4.46	0.5712
Preterm birth		Adequate prenatal care				
	≥ 37 weeks	Adequate	1.00			
		Intermediate	0.98	0.86	1.11	0.7284
		Inadequate	1.44	1.10	1.88	0.0075
	< 37 weeks	Adequate	1.00			
		Intermediate	0.93	0.61	1.42	0.7357
		Inadequate	2.09	0.77	5.66	0.1464

* Adjusted for all covariates.

연세대학교
YONSEI UNIVERSITY

4. Effects of postpartum readmission and severe maternal morbidity

1) The cumulative incidence of postpartum readmission

Figure 4 shows the Kaplan-Meier curve of postpartum readmission within 6 weeks after delivery according to SMM. The incidence of postpartum readmission was significantly higher in women who had SMM during delivery hospitalization than in those who did not have SMM (P<0.0001).

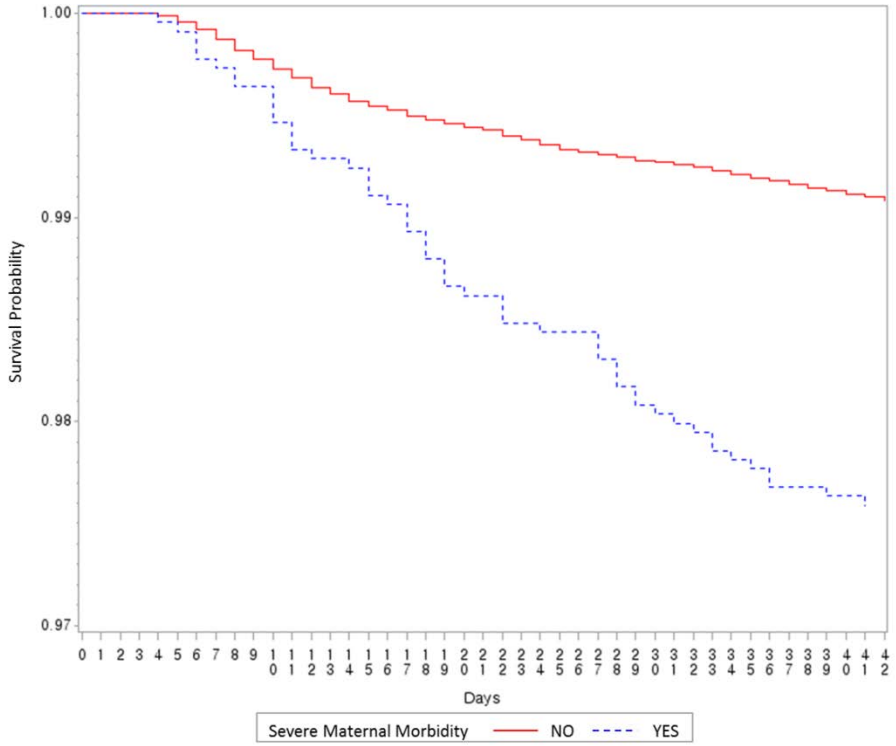

Figure 4. The Kaplan-Meier curve for postpartum readmission by severe maternal morbidity

연세대학교
YONSEI UNIVERSITY

2) Distribution of general characteristics and postpartum readmission

Table 12 shows the distribution of general characteristics and postpartum readmission occurrence. Of the 91,767 women included, 876 (0.95%) experienced postpartum readmission during the first 6 weeks after delivery. The proportion of postpartum readmission was higher in women who had SMM (2.40%), who had adequate prenatal care (0.99%), who were living in an area with both labor and obstetrics facilities (1.31%), and who had weekend or holiday delivery (1.01%).

Regarding individual factors, women aged 30 to 34 had the lowest rate of postpartum readmission (0.84%) (Table 12). On the other hand, teens and those aged 40 to 44 years old had higher rates of postpartum readmission (1.94%, and 1.28%, respectively). The lowest income levels had the highest rates of postpartum readmission (1.01%), and women with medical aid had a higher rate of postpartum readmission (1.36%) compared with employee or self-employed insured women (0.98%, and 0.94%, respectively). Women living in rural areas had a higher rate of postpartum readmission (1.01%).

In obstetric history and performance, instrumental delivery and cesarean section delivery were associated with higher rates of hospital readmission during the postpartum period (1.04%, and .95% respectively). Moreover, women who were nulliparous (1.06%), were discharged late after delivery hospitalization (1.14%), had preterm births before 37 weeks of gestation (1.17%), had comorbidities during pregnancy (1.14%), intrapartum

연세대학교
YONSEI UNIVERSITY

complications (1.11%), and postpartum complications (2.25%) had higher rates of postpartum readmission (Table 12).

Regarding hospital characteristics, general hospitals with more than 500 beds had higher rates of postpartum readmission (1.37%). Furthermore, teaching hospitals (1.28%), public hospitals (1.26%), hospitals located in rural areas (1.00%), and the Jeolla (1.33%), Gangwon (1.15%), and Jeju regions (1.00%) had higher rates of postpartum readmission (Table 12).

3) The relationship between postpartum readmission and risk factors

Table 12 presents the results of the Cox proportional hazards analysis with a robust variance-covariance matrix to account for repeated measures of individuals for postpartum readmission. The risk of postpartum readmission was significantly higher in women who had SMM during delivery hospitalization than in those who did not have SMM (HR 2.29, 95% CI 1.70-3.10, P<0.006). In prenatal care, women who had intermediate prenatal care had a lower hazard of SMM compared with those who had adequate prenatal care (HR 0.82, 95% CI 0.68-0.99, P = 0.0383). However, access to obstetrics facilities and time and day of delivery were not significantly associated with postpartum readmission.

Regarding maternal age, women aged 25 to 29 years had a 1.27 times higher risk of postpartum readmission compared with those aged 30 to 34 years (HR 1.27, 95% CI 1.08-1.48, P = 0.0031); teen mothers (15 to 19 years), women aged 20-24 years or 40 to

연세대학교
YONSEI UNIVERSITY

44 years old had higher risks of postpartum readmission; however, there were no significant associations. In addition, the risk of postpartum readmission was significantly higher in women with postpartum complications (HR 3.61, 95% CI 3.14-4.15, p<0.0001) (Table 12).

Regarding the hospital factors, general hospitals with more than 500 beds, and with less than 500 beds were associated with postpartum hospital readmission (HR 2.05, 95% CI 1.53-2.74, p<0.0001; and HR 1.38, 95% CI 1.00-1.90, p = 0.0053). Other hospital characteristics had no significant associations.

연세대학교
YONSEI UNIVERSITY

Table 12. The relationship between severe maternal morbidity and postpartum hospital readmission using Cox proportional hazard model

	Postpartum readmission					
	Total	**N**	**HR**	**95% CI**		**P-value**
Severe maternal morbidity						
No	89519	822	1.00			
Yes	2248	54	2.29	1.70	3.10	<.0001
Adequacy of prenatal care						
Adequate	72801	721	1.00			
Intermediate	17099	141	0.82	0.68	0.99	0.0383
Inadequate	1867	14	0.69	0.40	1.19	0.1819
Access to labor or obstetrics facility						
Both of None	1597	21	1.23	0.79	1.91	0.3615
Only obstetrics	1407	14	1.03	0.60	1.77	0.9076
Both	88763	841	1.00			
Day/time of delivery						
Weekday daytime	80005	759	1.00			
Weekday nighttime	8683	86	0.97	0.77	1.23	0.8087
Weekend or holiday	3079	31	0.99	0.68	1.43	0.9401
Individual factors						
Maternal age (years)						
15-19	310	6	2.13	0.92	4.91	0.0770
20-24	4213	50	1.34	0.99	1.82	0.0600
25-29	28654	313	1.27	1.08	1.48	0.0031
30-34	43202	363	1.00			
35-39	13526	121	1.04	0.84	1.28	0.7268
40-44	1795	23	1.34	0.88	2.06	0.1784
45-49	67	0	-	-	-	
Income level						
1Q	8629	89	0.98	0.74	1.30	0.8889
2Q	13430	134	0.97	0.76	1.24	0.8140
3Q	24017	220	0.93	0.75	1.15	0.4738
4Q	29897	288	1.01	0.83	1.24	0.9103
5Q	15794	145	1.00			
Type of insurance						
Self-employed insured	26773	263	1.06	0.91	1.22	0.4686
Employee insured	64700	609	1.00			
Medical aid	294	4	1.20	0.43	3.34	0.7305

연세대학교
YONSEI UNIVERSITY

Table 12. The relationship between severe maternal morbidity and postpartum hospital readmission using Cox proportional hazard model *(continued)*

	Postpartum readmission					
	Total	**N**	**HR**	**95% CI**		**P-value**
Residential area						
Metropolitan (Seoul)	18372	153	1.00			
City	23009	215	1.19	0.93	1.53	0.1629
Rural	50386	508	1.17	0.91	1.51	0.2107
Working status						
Work	25524	261	1.08	0.93	1.27	0.3076
Not work	66243	615	1.00			
Obstetric factors						
Mode of delivery						
Spontaneous vaginal delivery	32547	290	1.00			
Instrumental delivery	24917	259	1.04	0.88	1.24	0.6331
Cesarean section delivery	34303	327	0.98	0.83	1.15	0.8000
Parity						
1 (Nulliparous)	61271	647	1.61	1.05	2.46	0.0279
2	27046	206	1.20	0.78	1.85	0.4122
3+	3450	23	0.79	0.45	1.39	0.4160
Twin birth status						
Singleton	90441	863	1.21	0.69	2.14	0.5014
Twin	1326	13	1.00			
Length of stay for delivery hospitalization			1.03	0.89	1.20	0.6880
Short term	6244	55	0.99	0.74	1.31	0.9153
Normal	61926	553	1.00			
Long term	23597	268	1.10	0.94	1.28	0.2247
Preterm birth						
≥ 37 weeks	90072	858	1.00			
< 37 weeks	1695	18	0.85	0.52	1.39	0.5220
Comorbidities during pregnancy						
0	90710	864	1.00			
1+	1057	12	0.86	0.48	1.55	0.6164

연세대학교
YONSEI UNIVERSITY

Table 12. The relationship between severe maternal morbidity and postpartum hospital readmission using Cox proportional hazard model *(continued)*

	Postpartum readmission					
	Total	**N**	**HR**	**95% CI**		**P-value**
Hospital factors						
Type of hospital						
Clinic (<30 beds)	20461	199	1.24	0.98	1.56	0.0782
Clinic (30≤beds<100)	22227	202	1.08	0.86	1.35	0.5195
Hospital (30≤beds<100)	15932	127	1.00			
Hospital (100≤beds<500)	16592	150	1.09	0.86	1.38	0.4886
General hospital (<500 beds)	6159	56	1.23	0.89	1.69	0.2181
General hospital (≥500 beds)	10396	142	1.65	1.28	2.14	0.0001
Hospital ownership						
Public	396	5	1.17	0.49	2.79	0.7298
Private, for -profit	91371	871	1.00			
Hospital location						
Urban	45524	413	1.00			
Rural	46243	463	1.05	0.86	1.29	0.6188
Hospital region						
Capital area	45595	415	1.00			
Gangwon region	2265	26	1.09	0.72	1.67	0.6818
Chungcheong region	9234	80	0.86	0.66	1.12	0.2594
Gyeongsang region	23469	210	0.92	0.76	1.11	0.3831
Jeolla region	10006	133	1.38	1.11	1.71	0.0036
Jeju region	1198	12	0.98	0.52	1.84	0.9536
Year						
2003	8526	77	1.00			
2004	8475	78	1.04	0.75	1.42	0.8298
2005	8193	82	1.15	0.84	1.58	0.3780
2006	8217	69	1.00	0.71	1.39	0.9775
2007	9019	92	1.23	0.89	1.69	0.2111
2008	8281	85	1.25	0.90	1.73	0.1893
2009	7570	69	1.13	0.80	1.59	0.5053
2010	7970	75	1.18	0.84	1.66	0.3380
2011	8653	83	1.22	0.87	1.71	0.2574
2012	8871	98	1.38	0.99	1.93	0.0603
2013	7992	68	1.08	0.75	1.55	0.6758

HR: hazard ratio

연세대학교
YONSEI UNIVERSITY

4) Subgroup analysis of severe maternal morbidity and postpartum readmission

Table 13 presents a subgroup analysis in which cox hazard ratio was performed to assess the relationship between SMM and postpartum readmission by adequacy of prenatal care, access to obstetric care, and time/day of delivery. Among those with adequate prenatal care, women with SMM had a significantly higher risk of postpartum readmission (HR 2.16, 95% CI 1.53-3.06, p<0.0001). Women who had intermediate prenatal care with SMM had a significantly higher risk of postpartum readmission (HR 2.33, 95% CI 1.15-4.71, p = 0.019). Particularly, women with SMM among those with inadequate prenatal care had a significantly higher risk of postpartum readmission (HR 11.86, 95% CI 2.03-69.27, p = 0.006).

Regarding access to obstetric care, women living in areas with both labor and obstetric facilities had a 2.2 times higher risk of postpartum readmission (HR 2.23, 95% CI 1.64-3.05, P<0.0001). However, women living in areas without either labor or obstetric facilities had a significantly higher risk of postpartum readmission compared with those without SMM (HR 9.34, 95% CI 1.86-47.00, P = 0.007) (Table 13).

Regarding time/day of delivery, among women who gave childbirth on weekdays in the daytime, those with SMM had a higher risk of postpartum readmission (HR 2.38, 95% CI 1.73-3.26), while women with SMM with weekend childbirth had approximately a 9 times higher risk of postpartum readmission (HR 8.98, 95% CI 2.14-

연세대학교
YONSEI UNIVERSITY

37.77, P = 0.003) (Table 13).

Regarding age, among women aged 25 to 29, 30 to 34, and 35 to 39, those with SMM had a higher risk of postpartum readmission (HR 2.94, 95% CI 1.75-4.93, P<0.0001; HR 1.83, 95% CI 1.09-3.06, P = 0.021; and HR 3.13, 95% CI 1.67-5.89, respectively). Among women with SMM who were teenagers and those over 40 years old, there was no significant association with postpartum readmission (Table 13).

Regarding mode of delivery, women who gave birth by spontaneous vaginal delivery, instrumental delivery, and cesarean section delivery with SMM had a significantly higher risk of postpartum readmission compared with those without SMM (HR 3.63, 95% CI 2.05-6.43, p<0.0001; HR 2.20, 95% CI 1.18-4.13, p = 0.014; and HR 1.94 95% CI 1.29-2.91, p = 0.001, respectively) (Table 13).

Regarding the length of stay for delivery hospitalization, women who had short-term delivery hospitalization with SMM had a 5.6 times higher risk of postpartum readmission (HR 5.61, 95% CI 1.78-17.73, p = 0.003), and women who had normal and long-term delivery hospitalization with SMM had a significant association with postpartum readmission (HR 2.38 95% CI 1.48-3.82, p = 0.0001; and HR 1.97, 95% CI 1.30-2.99, p = 0.0014) (Table 13).

연세대학교
YONSEI UNIVERSITY

Table 13. The result of subgroup analysis for postpartum readmission

		Postpartum readmission			
		HR	**95% CI**		**P-value**
Adequacy of prenatal care	Severe maternal morbidity				
Adequate	No	1.00			
	Yes	2.16	1.53	3.06	<.0001
Intermediate	No	1.00			
	Yes	2.33	1.15	4.71	0.0187
Inadequate	No	1.00			
	Yes	11.86	2.03	69.27	0.0060
Access to labor or obstetrics facility	Severe maternal morbidity				
Both of None	No	1.00			
	Yes	9.34	1.86	47.00	0.0067
Only obstetrics	No	1.00			
	Yes	-	-	-	
Both	No	1.00			
	Yes	2.23	1.64	3.05	<.0001
Time/days of delivery	Severe maternal morbidity				
Weekdays daytime	No	1.00			
	Yes	2.38	1.73	3.26	<.0001
Weekdays nighttime	No	1.00			
	Yes	0.85	0.21	3.40	0.8129
Weekend	No	1.00			
	Yes	8.98	2.14	37.77	0.0027

연세대학교
YONSEI UNIVERSITY

Table 13. The result of subgroup analysis for postpartum readmission *(continued)*

		Postpartum readmission			
		HR	**95% CI**		**P-value**
Age (years)	Severe maternal morbidity				
15-19	No	1.00			
	Yes	-	-	-	
20-24	No	1.00			
	Yes	0.99	0.17	5.92	0.9935
25-29	No	1.00			
	Yes	2.94	1.75	4.93	<.0001
30-34	No	1.00			
	Yes	1.83	1.09	3.06	0.0212
35-39	No	1.00			
	Yes	3.13	1.67	5.89	0.0004
40-44	No	1.00			
	Yes	2.23	0.59	8.50	0.2404
45-49	No	1.00			
	Yes	-	-	-	
Mode of delivery	Severe maternal morbidity				
Spontaneous vaginal delivery	No	1.00			
	Yes	3.63	2.05	6.43	<.0001
Instrumental delivery	No	1.00			
	Yes	2.20	1.18	4.13	0.0137
Cesarean section delivery	No	1.00			
	Yes	1.94	1.29	2.91	0.0014
Delivery discharge	Severe maternal morbidity				
Early	No	1.00			
	Yes	5.61	1.78	17.73	0.0033
Normal	No	1.00			
	Yes	2.38	1.48	3.82	0.0004
Late	No	1.00			
	Yes	1.97	1.30	2.99	0.0014
Working status	Severe maternal morbidity				
Work	No	1.00			
	Yes	2.47	1.44	4.23	0.0010
Not work	No	1.00			
	Yes	2.23	1.55	3.19	<.0001

HR: hazard ratio
Adjusted for all covariates

연세대학교
YONSEI UNIVERSITY

Ⅴ. Discussion

1. Discussion of study methods

In this study with a representative large nationwide sample of a cohort of Korean women, we found that indicators for quality of care, and individual, obstetric, and hospital factors were associated with SMM. Moreover, SMM was associated with a higher risk of postpartum readmission. The methods used in this study had distinctive features that need to be highlighted.

First, the data used were collected from a nationally representative population-based sample cohort from 2002 to 2013. Many previous studies used a variety of data such as population-, community-, or hospital-based data. Most studies followed just a few years and did not include long-term follow-up data; however, this analysis used population-based, long-term follow-up data. Moreover, the data contained significantly exact death points because they were matched to mortality information from the Korean National Statistical Office, although de-noted day of death presented a limitation.

Second, this study considered integrated factors that influenced maternal health outcomes, and various objective indicators and databases were used. Many studies have measured the relationship between socio-demographic or obstetric performance and maternal health outcomes. However, this research estimated the association not only of socio-demographic, obstetric, and hospital factors, but quality indicators such as

연세대학교
YONSEI UNIVERSITY

geographic accessibility, prenatal care as an indicator of effectiveness, day/time of delivery as an indicator of timing, and maternal health outcomes.

Third, this study used a GEE model with logit link using an autoregressive correlation structure for repeated measures. In most previous studies, participants provided data just once concerning parity, that is whether they were nulliparous or not. However, the present study followed up women's parity over 11 years, and analyzed whether women delivered repeatedly. It could estimate correlations between the first birth, and second and more births within a person as well as parity for each individual. Regarding postpartum readmission, the present study also used Cox proportional hazard models with a robust variance-covariance matrix to account for considering repeated measures of individuals.

연세대학교
YONSEI UNIVERSITY

2. Discussion of study results

In this study, we confirmed that quality indicators, and individual, obstetrics, and hospital factors were related to SMM. Women who received inadequate prenatal care and who delivered on weekdays at nighttime, on weekends, or on holidays had a significantly higher SMM incidence. In addition, regarding individual socio-demographic and obstetric factors, women who delivered at an extremely young or old age, who had low levels of family income, who delivered by cesarean section, who were nulliparous, who had multiple births, who had long-term delivery hospitalization, and who had comorbidities during pregnancy had a high risk of SMM. Moreover, women who delivered at large volume hospitals or small clinics, at teaching hospitals, at hospitals in the Gyeongsang and Jeolla regions that are away from the Capital area had a high risk of SMM.

The incidence of SMM was 2.45% of total maternity in this study. This was similar to some previous research although other studies had different results. Howell and colleagues, and Ozimek and colleagues reported 2.5%, 2%, and 2.4% of their study populations with SMM, respectively [32,88,99] although Norhayati and colleagues, Zwart and colleagues, and Grobman and colleagues showed 1.7%, 0.7%, and 0.3% of their study populations with SMM, respectively [33,35,100]. The incidence of SMM differed because of differences in the study population, maternal health conditions in the countries or

연세대학교
YONSEI UNIVERSITY

communities, and use of different SMM indicators such as the CDC's algorithm or WHO's indicators. This study used the CDC's algorithm as an SMM indicator, and the incidence of SMM was similar to those studies using the same SMM indicators. Additionally, we confirmed the relationship between risk factors and the sub-indicators of SMM. Blood transfusion was the most frequent indicator in almost 60% of all cases of SMM. Disseminated intravascular coagulation occurred in 9% of total SMM cases. The results of this study were similar to a previous study. The New York City Department of Health and Mental Hygiene reported that blood transfusion accounted for roughly 65% of all SMM cases, and other previous studies showed that blood transfusion was the most common indicator of SMM [34,83].

This study confirmed that inadequate prenatal care and risk of SMM had statistically significant associations. However, there was less evidence of an association between prenatal care and SMM using CDC's algorithm. Howell and colleagues reported that women who visited obstetrics less than 6 or 6 to 8 times had a higher occurrence of SMM than those who visited obstetrics more than 9 times, with odds ratios of 1.34 and 1.16, respectively [27]. WHO evaluated antenatal care (ANC) and found that more than one to 4 or more ANC visits reduced maternal mortality and improved quality of maternal health care [8,101]. In Kearns' study, high-quality maternal care, in terms of accessibility and acceptability of ANC and postnatal care (PNC), improved health outcomes [101]. To

연세대학교
YONSEI UNIVERSITY

facilitate this, available indicators such as the average number of ANC or PNC visits and the approximate timing of the first ANC visit can be used for assessment [101]. Unfortunately, there is no consensus on the definition of quality and its measurement [102]. Therefore, the results of this study might provide evidence to improve the quality of maternal health care through the relationship between prenatal care and SMM as a maternal health outcome.

Even though the relationship between access to labor and/or obstetric facilities and SMM was not significant, previous research showed remoteness from residence and SMM were related to SMM. In Lindquist et al.'s study, there was a significant association between remoteness of residence from labor and/or obstetric facilities and SMM, especially in the lowest SEIFA, for which geographic access and socio-economic status had a significant association with SMM [31]. Geographic distance from labor and/or obstetric facilities and SMM were not significantly associated, but access to services could affect disadvantaged women [31]. There are several possible reasons for differences in the results of this study and those of previous studies. In this study, there were some cities without labor and/or obstetric facilities. In other words, although there was no problem of access, there is still an issue of disparities between areas. Another possibility was that deliveries were not recorded in areas with these disparities, so no significant associations were found. In fact, the opening and closing of hospitals is decided by the

연세대학교
YONSEI UNIVERSITY

market economy. In areas with disparities, if rates of women's fertility or the number of births were low, it is not possible to select samples. However, if the region does not have obstetric facilities, women who live in that region have difficulty seeing an obstetrician. Moreover, if they have more direct- and indirect-costs for prenatal care, obstetrics visits could be reduced; as a result, these factors might adversely influence maternal health outcomes during the postpartum period.

This study could confirm the relationship between day/time of delivery as an indicator of timing and risk of SMM. Women who delivered on a weekday at nighttime and on weekends or holidays had a higher risk of SMM compared with those who delivered on a weekday in the daytime. To our knowledge, there was no previous evidence of an association between day/time of delivery and SMM. However, Palmer and colleagues showed that puerperal infection was higher for delivery on Saturday than Tuesday [96], and Snowden and colleagues reported that severe maternal and neonatal complications increased on high-volume days and weekends adjusted for maternal demographics, annual hospital birth volume, and teaching hospital status [103]. In Palmer's study, if the effect was caused by a staff deficiency and a lack of resources, one would expect poorer quality and safety during all out-of-hours periods during the week. Palmer's study provided some evidence to support the theory that one of the contributing factors to the weekend effect might be a failure to meet recommended levels of consultant presence,

연세대학교
YONSEI UNIVERSITY

with a significant association between staffing and perinatal tear rates [96]. There might be an explanation of some of the mechanisms underlying the high risk of SMM on weekday nighttime and weekend delivery, even though the exact reasons for the weekend effect are not known. Nursing and physician staffing might include less experienced people on weekend shifts in the hospital. Another reason might be there are fewer nurses and doctors on the weekend. Our data do not allow us to show which of these things could be linked to worse care. In Cram's study, patients admitted on weekends had a slightly higher risk-adjusted mortality compared with those on weekdays [104]. In Cram's research, the weekend effect reflected more than physician availability on weekends. It more likely reveals integrated factors that result in reduced quality of care, decreased levels of staffing, reduced availability of certain procedures, and an overall reduction in patient supervision when hospital staffing decreases during the weekend [104]. Similarly, SMM might occur through delivery failure or failure of early postpartum management caused by a lack of resources and staff on weekends. In fact, South Korea is undergoing a reduction of obstetricians and labor facilities because of extremely low fertility rates and low insurance reimbursement of delivery procedures; therefore, the weekend effect of delivery might be a natural result in this study.

This study found that several other factors are significantly associated with risk of SMM, including being aged below 20 or over 35 years, low level of family income,

연세대학교
YONSEI UNIVERSITY

cesarean section delivery, nulliparity, twin births, and long-term delivery hospitalization. Regarding obstetric factors, cesarean section delivery had a 2.5 times higher risk of SMM, similar to previous studies [31,33,105].

Cesarean section delivery is a well-known risk factor for maternal morbidity and mortality compared with vaginal delivery [25,31,33,106] because it is related to hemorrhaging [25]. Similar results were found in the subgroup analysis by procedure-based SMM in this study. Blood transfusion was the most frequent event of SMM, and cesarean section delivery with blood transfusion was significantly related to higher risk of SMM compared with vaginal delivery.

Parity was significantly associated with SMM. Nulliparous women had a 1.2 times higher risk of SMM compared with multiparous women who had second births. However, there was no statistically significant association for multiparous women who had third and more births. Previous studies showed similar results to ours. Multiparous women had a 0.96, or 0.68 times lower risk of SMM compared with nulliparous women [27,99], nulliparous women had a 1.38, or 1.8 times higher risk of SMM compared with multiparous women [35,40], and nulliparous women had a 1.4 times higher and multiparous women who had more than 3 births had an approximately 2 times higher risk of SMM compared with multiparous women who had their 2nd birth [105]. Moreover, in the subgroup analysis, nulliparous women who had inadequate prenatal care had a 1.4 times higher risk

연세대학교
YONSEI UNIVERSITY

of SMM compared with those who had adequate prenatal care. Nulliparity is one of the risk factors for adverse maternal health outcome [27,35,99,105]; therefore, it needs to be monitored carefully for maternal health care during pregnancy.

Twin birth was significantly associated with SMM. This study found that twin or triplet birth was associated with a 1.8 times higher risk of SMM compared with singleton birth, similar to previous studies. Santana and colleagues showed that through a cross-sectional WHO multi-country survey, twin pregnancy was related to greater SMM and a higher rate of maternal death than singleton pregnancy [39], Witteveen and colleagues showed that women with multiple pregnancies had a more than 4 times elevated risk of severe acute maternal mobility compared with singletons through a population-based cohort study [40], and Joseph and colleagues showed that twin or more than triplet birth was associated with a 3.3 times, and 6.2 times higher risk of SMM compared with singleton birth, respectively [105]. The mechanisms for the relationship between twin birth and greater SMM can be explained. First, maternal complication such as obstetric hemorrhage, chronic hypertension, pre-eclampsia and eclampsia, postpartum hemorrhage, and severe anemia are commonly known to be associated with twin birth [38,39,107]. Only postpartum hemorrhage and chronic hypertension were related to twin pregnancy whether women had SMM or not [39]. Regarding social phenomena, the increased incidence of twin birth rates among women aged more than 35 years old results from physiological endogenous

연세대학교
YONSEI UNIVERSITY

ovarian hyperstimulation and greater use of assisted reproductive techniques (ART) for infertility [38,39]. Twin pregnancies with ART are more likely to be associated with older age, cesarean section delivery, and having maternal complication such as obstetric hemorrhage; therefore, they might be associated with SMM, which is similar to our results.

Regarding maternal age, the risk of SMM had a J-shaped distribution related to maternal age, which was similar to previous studies [26,33,35,105]. The mechanism linking advanced maternal age (defined as 35 years or older) and high risk of SMM is often related to increased risk of placental abruption or abnormally invasive placenta [108], and there is a lack of physiological reverses in response to pregnancy pathology, as well as more chance of chronic diseases [26,29]. Maternal adverse risk was also associated with the extremely low age of 15-19 years old. The mechanism could be that teenage mothers have increased risks for pre-term delivery, low birth weight [109], poverty, low education level, inadequate prenatal care, and unmarried status [110,111]. Moreover, immaturity of the uterine or cervical blood supply in teen-pregnancy could raise the risk of subclinical infection and prostaglandin production, and lead to increased risk of preterm delivery [109]. Therefore, these factors might explain why women aged 15-19 years old had a higher risk of SMM.

Regarding income level, women with the lowest income level had a higher risk

연세대학교
YONSEI UNIVERSITY

of SMM compared with those with the highest income level. A previous study showed that low SES women were more likely to have a high risk of SMM compared with high SES women [31]. This could be because women in the lowest SES group commonly report poorer experiences of care during pregnancy, have higher risks of prenatal hospital admission, and receive less prenatal care or are less likely to meet a midwife or GP for a 6-8 weeks postnatal review [112]. As a result, disparities in health-seeking behavior, access to maternity services, and treatment of women by healthcare professionals could contribute to maternal health outcomes [113]. This mechanism could explain our results. In the subgroup analysis by income level, women whose income levels were mid-low (2Q: second quartile) with inadequate prenatal care had a 2 times higher risk of SMM compared with those with adequate prenatal care. In addition, this study could not find a relationship between teenage mothers and inadequate prenatal care in SMM because of limitations of estimation; however, this study found that women aged 20-24 years old had a higher risk of SMM when they had intermediate or inadequate prenatal care compared with those who had adequate prenatal care. Considering this result, it is possible that young mothers were more likely to have low income levels, be less educated, nulliparous, and lack access to obstetric care. Finally, maternal age, low income levels, and inadequate prenatal care were intertwined with other factors, and affected maternal health outcomes. Interestingly, women aged over 35 years had a higher risk of SMM.

연세대학교
YONSEI UNIVERSITY

Even though access to obstetric facilities and time/day of delivery were not associated with postpartum hospital readmission, SMM was positively correlated with postpartum readmission. In addition, mothers aged 25 to 29 had a higher risk of postpartum readmission than those aged 30 to 34 years, and nulliparous women had a higher risk of postpartum readmission compared with multiparous women. In subgroup analysis, we found that women who had SMM had a 1.4 times and 3.2 times higher risk of postpartum readmission, respectively, whether women had adequate or inadequate prenatal care. Regarding access to labor or obstetric facilities, women with SMM had a higher risk of postpartum readmission whether their region had both labor and obstetric facilities or neither. However, the hazard effect size was significantly higher in women living in regions without any labor and obstetric facilities. In addition, women with SMM who delivered on weekends had a significantly higher risk of postpartum readmission, and women who delivered on weekdays during the daytime with SMM had a higher risk of postpartum readmission compared with those without SMM. Regarding age, women over 25 years with SMM had a higher risk of postpartum readmission, even though there was no significant association in women aged 30-34 and over 40 years. Moreover, women who had spontaneous vaginal delivery with SMM who had short-term delivery hospitalization had quite a high risk of postpartum readmission.

연세대학교
YONSEI UNIVERSITY

3. Limitations and strengths of the study

This study has several limitations. First, for assessment of SMM, we used administrative data (ICD-10) that do not include important clinical data on severity of illness; therefore, we did not define the severity of SMM. Furthermore, we used a published algorithm to identify SMM cases and did not conduct a medical chart review for case ascertainment. Second, we could not adjust for potential confounders such as maternal education level, body mass index, and behavior risk factors (smoking or alcohol drinking), which the data did not contain. Nevertheless, we performed a population-based cohort study and could construct a risk-adjustment that included important confounders available in our linked data set. Third, the data did not contain gestation commencement dates so the duration of pregnancy could be not calculated exactly. Moreover, in preterm births before 37 weeks of gestation, we could not know the exact length of pregnancy to determine whether extremely early preterm birth occurred or not. However, because our data contains the exact date of birth, we could estimate the first pregnancy period by calculating the gestation period. Additionally, we conducted sensitivity analysis for the preterm birth period, although there was not much difference between 28 weeks and 36 weeks for SMM. Fourth, there is a problem with conversion of ICD-9 procedure codes. The NHIS-NSC used ICD-10 codes that did not include procedure codes; therefore, we converted ICD-9 procedure codes to EDI codes in this dataset. During the conversion

연세대학교
YONSEI UNIVERSITY

process, some cases had no information with an EDI code, therefore, some procedure-based SMM cases might have been less exact. Fifth, to estimate accessibility to obstetric facilities, we used 3 categories: women who lived in a region with both labor and obstetric facilities, who lived in a region without labor but with obstetrics facilities, and who lived in a region without either labor or obstetric facilities. We found that even though some regions did not have labor facilities, they were in the administrative district of a large city and a delivery hospital could be reached in an hour. Therefore, further research should consider using a more elaborate classification scheme and definition of accessibility to labor facilities. Sixth, in the statistical analysis, causal relationships were estimated with a GEE model and Cox proportional hazard model. However, the relationship between SMM during delivery hospitalization and some risk factors might run in same pathway. Therefore, further studies will be able to use a classification analysis to identify high risk women with SMM to predict risk of SMM.

Nevertheless, this study has some strengths. First, to our knowledge, this is the first study of SMM considering quality factors, and the first study of SMM in Korea. Until recently, there has been less evidence regarding SMM using any quality indicators. This study provides important evidence for use in future maternal health care. Second, it has a population-based design, long-term follow up, and data that were obtained from the NHIS-NSC that are nationally representative. Third, we tried to use objective indicators

연세대학교
YONSEI UNIVERSITY

or databases to adjust for various health care quality factors, particularly, the Kessner Adequacy of Prenatal Care Index was calculated for effectiveness from NHIS-NSC data, access to labor or obstetric facilities was linked to national data from HIRA, and exact delivery day and time could be estimated for timing from NHIS-NSC data. Fourth, we tried to consider various obstetric comorbidities and provision factors to adjust for case mix.

연세대학교
YONSEI UNIVERSITY

4. Policy implications

Adequate prenatal care, geographical, and financial access to obstetrics facilities, and timeliness of and resources for delivery are important factors for quality of care to improve maternal health outcomes during and after delivery. In fact, South Korea has made various policy interventions to increase the low fertility rate, such as financial voucher services for maternity, designation and support to geographically vulnerable areas for childbirth, and expending insurance coverage for high risk maternity. Particularly, the purpose of financial voucher services is to encourage increased maternal care during or after pregnancy, although it is not totally for prenatal care. Therefore, it is necessary to understand and encourage mothers to follow guidelines for adequate prenatal care, provide inducements to use financial voucher services during the prenatal period, and provide monitoring and evaluation for the average number of prenatal care visits during each trimester.

Another issue concerns resources and infrastructure in South Korea. Recently South Korea has experienced problems with insufficient human resources and lack of labor facilities. Considering factors including avoidance of the obstetrics area by medical students, reduction of labor and obstetric facilities because of low fertility, and high-risk procedures but low insurance premium rates for obstetricians, there has been a decrease in professional human resources and labor and obstetric facilities caused by the market

연세대학교
YONSEI UNIVERSITY

economy. Most deliveries are urgent and it is difficult to know when a maternal emergency will occur so it is important to provide access to labor facilities and to allocate professional human resources. Therefore, the government should provide more support to geographically vulnerable areas in terms of both facilities and obstetricians, and should encourage obstetricians through rewards for urgent and risky procedures.

Lastly, the quality indicators for maternity are insufficient. In fact, there are few indicators for quality of maternal health care not only in South Korea but also in developed countries such as the US. However, many researchers are studying how to improve maternal health care, and to improve the quality related to satisfaction, dignity, and rights for mothers and newborns. Therefore, policy makers should consider maternal health care not only in terms of physical but mental health, as well as emotional satisfaction, and mothers' rights and dignity as human beings when they formulate maternal health care policies and quality indicators for maternal care.

연세대학교
YONSEI UNIVERSITY

Ⅵ. Conclusion

Inadequate prenatal care delivery was associated with the occurrence of severe maternal morbidity during delivery hospitalization. In addition, weekday nighttime or weekend delivery was related to the risk of severe maternal morbidity. Moreover, women with severe maternal morbidity had a higher risk of postpartum readmission. Therefore, policy makers should consider formulating quality indicators for timely, adequate, and sufficient visits during pregnancy, should monitor adequacy of prenatal care to prevent severe maternal morbidity and to improve the quality of maternal health care, and should provide financial and systemic support to allocating adequate human resources and labor facilities in vulnerable areas as well as during weekends or the nighttime to improve the quality of intrapartum and postpartum maternal care.

연세대학교
YONSEI UNIVERSITY

References

1. Statistics Korea. *Pulation Trend Survey (Korean).* Republic of Korea: Statistics Korea;2016.
2. OECD. *"Maternal mortality", in Health at a Glance: Asia/Pacific 2016: Measuring Progress towards Universal Health Coverage.* Paris: OECD Publishing;2016.
3. United Nations. *World Population Policies 2013.* New York, United States: United Nations;2013.
4. Yang J-M. A strategy for improvement of population quality. *Korean Journal of Public Health.* 1984;37:1-17.
5. Alkema L, Chou D, Hogan D, et al. Global, regional, and national levels and trends in maternal mortality between 1990 and 2015, with scenario-based projections to 2030: a systematic analysis by the UN Maternal Mortality Estimation Inter-Agency Group. *The Lancet.* 2016;387(10017):462-474.
6. Kassebaum NJ, Bertozzi-Villa A, Coggeshall MS, et al. Global, regional, and national levels and causes of maternal mortality during 1990–2013: a systematic analysis for the Global Burden of Disease Study 2013. *The Lancet.* 2014;384(9947):980-1004.
7. UN Development Program. Sustainable Development Goals. 2015.
8. Campbell OM, Calvert C, Testa A, et al. The scale, scope, coverage, and capability of childbirth care. *The Lancet.* 2016;388(10056):2193-2208.
9. WHO, UNICEF. *Trends in maternal mortality: 1990 to 2013: WHO, UNICEF, UNFPA and The World Bank estimates.* Geneva, Switzerland: World Health Organization; 2014.
10. Souza JP, Cecatti JG, Haddad SM, et al. The WHO maternal near-miss approach and the maternal severity index model (MSI): tools for assessing the management of severe maternal morbidity. *PLoS One.* 2012;7(8):e44129.
11. PS R, Verma S, Rai L, Kumar P, Pai MV, Shetty J. “Near Miss” Obstetric Events and Maternal Deaths in a Tertiary Care Hospital: An Audit. *Journal of Pregnancy.* 2013;2013:1-5.
12. Stones W, Lim W, Al-Azzawi F, Kelly M. An investigation of maternal morbidity with identification of life-threatening'near miss' episodes. *Health trends.* 1990;23(1):13-15.
13. Lawn JE, Blencowe H, Pattinson R, et al. Stillbirths: Where? When? Why? How to make the data count? *The Lancet.* 2011;377(9775):1448-1463.
14. Ronsmans C, Graham WJ, group LMSSs. Maternal mortality: who, when, where, and why. *The lancet.* 2006;368(9542):1189-1200.
15. Welt SI, Cole JS, Myers MS, Sholes DM, Jelovsek FR. Feasibility of postpartum rapid hospital discharge: a study from a community hospital population. *American journal of perinatology.* 1993;10(5):384-387.
16. Fortney JA, Susanti I, Gadalla S, Saleh S, Rogers SM, Potts M. Reproductive mortality in two developing countries. *American journal of public health.* 1986;76(2):134-138.
17. Hill K, Thomas K, AbouZahr C, et al. Estimates of maternal mortality worldwide between 1990 and 2005: an assessment of available data. *The Lancet.* 2007;370(9595):1311-1319.
18. Kilpatrick SK, Ecker JL, Obstetricians ACo, Gynecologists. Severe maternal morbidity: screening and review. *American journal of obstetrics and gynecology.* 2016;215(3):B17-B22.

연세대학교
YONSEI UNIVERSITY

19. Mantel GD, Buchmann E, Rees H, Pattinson RC. Severe acute maternal morbidity: A pilot study of a definition for a near-miss. *BJOG: An International Journal of Obstetrics & Gynaecology.* 1998;105(9):985-990.
20. Pattinson R, Say L, Souza JP, Broek Nvd, Rooney C. WHO maternal death and near-miss classifications. *Bulletin of the World Health Organization.* 2009;87(10):734-734A.
21. Callaghan WM, Creanga AA, Kuklina EV. Severe maternal morbidity among delivery and postpartum hospitalizations in the United States. *Obstetrics & Gynecology.* 2012;120(5):1029-1036.
22. Center for Disease Control and Prevention. Severe maternal morbidity in the United States. https://www.cdc.gov/reproductivehealth/maternalinfanthealth/severematernalmorbidity.html. Accessed 13 April, 2017.
23. Say L, Souza JP, Pattinson RC. Maternal near miss–towards a standard tool for monitoring quality of maternal health care. *Best Practice & Research Clinical Obstetrics & Gynaecology.* 2009;23(3):287-296.
24. WHO. *Evaluating the quality of care for severe pregnancy complications: The WHO near-miss approach for maternal health.* Geneva: World Health Organization; 2011.
25. Siddiqui M, Minhaj M, Mueller A, et al. Increased perinatal morbidity and mortality among Asian American and Pacific Islander women in the United States. *Anesthesia & Analgesia.* 2017;124(3):879-886.
26. Creanga AA, Bateman BT, Kuklina EV, Callaghan WM. Racial and ethnic disparities in severe maternal morbidity: a multistate analysis, 2008-2010. *American journal of obstetrics and gynecology.* 2014;210(5):435. e431-435. e438.
27. Howell EA, Egorova NN, Balbierz A, Zeitlin J, Hebert PL. Site of delivery contribution to black-white severe maternal morbidity disparity. *American journal of obstetrics and gynecology.* 2016;215(2):143-152.
28. Van Hanegem N, Miltenburg AS, Zwart JJ, Bloemenkamp KW, Van Roosmalen J. Severe acute maternal morbidity in asylum seekers: a two-year nationwide cohort study in the Netherlands. *Acta obstetricia et gynecologica Scandinavica.* 2011;90(9):1010-1016.
29. Kayem G, Kurinczuk J, Lewis G, Golightly S, Brocklehurst P, Knight M. Risk factors for progression from severe maternal morbidity to death: a national cohort study. *PLoS One.* 2011;6(12):e29077.
30. de Moraes APP, Barreto SM, Passos VMA, Golino PS, Costa JE, Vasconcelos MX. Severe maternal morbidity: a case-control study in Maranhao, Brazil. *Reproductive health.* 2013;10(1):11.
31. Lindquist A, Noor N, Sullivan E, Knight M. The impact of socioeconomic position on severe maternal morbidity outcomes among women in Australia: a national case–control study. *BJOG: An International Journal of Obstetrics & Gynaecology.* 2014;122(12):1601-1609.
32. Howell EA, Egorova N, Balbierz A, Zeitlin J, Hebert PL. Black-white differences in severe maternal morbidity and site of care. *American journal of obstetrics and gynecology.* 2016;214(1):122. e121-122. e127.
33. Norhayati MN, Hazlina NHN, Aniza AA, Sulaiman Z. Factors associated with severe maternal morbidity in Kelantan, Malaysia: A comparative cross-sectional study. *BMC Pregnancy and Childbirth.* 2016;16(1):185.
34. Callaghan WM, MacKay AP, Berg CJ. Identification of severe maternal morbidity during delivery hospitalizations, United States, 1991-2003. *American journal of obstetrics and*

연세대학교
YONSEI UNIVERSITY

gynecology. 2008;199(2):133. e131-133. e138.
35. Grobman WA, Bailit JL, Rice MM, et al. Frequency of and factors associated with severe maternal morbidity. *Obstetrics and gynecology.* 2014;123(4):804-810.
36. Kilpatrick SJ, Abreo A, Greene N, et al. Severe maternal morbidity in a large cohort of women with acute severe intrapartum hypertension. *American journal of obstetrics and gynecology.* 2016;215(1):91. e91-91. e97.
37. Kominiarek MA, Scott S, Koch AR, et al. Preventing Maternal Morbidity from Obstetric Hemorrhage: Implications of a Provider Training Initiative. *American journal of perinatology.* 2017;34(01):74-79.
38. Martin AS, Monsour M, Kissin DM, Jamieson DJ, Callaghan WM, Boulet SL. Trends in severe maternal morbidity after assisted reproductive technology in the United States, 2008–2012. *Obstetrics & Gynecology.* 2016;127(1):59-66.
39. Santana DS, Cecatti JG, Surita FG, et al. Twin Pregnancy and Severe Maternal Outcomes. *Obstetrics & Gynecology.* 2016;127(4):631-641.
40. Witteveen T, Van Den Akker T, Zwart JJ, Bloemenkamp KW, Van Roosmalen J. Severe acute maternal morbidity in multiple pregnancies: a nationwide cohort study. *American journal of obstetrics and gynecology.* 2016;214(5):641. e641-641. e610.
41. Norhayati MN, Hazlina NHN, Sulaiman Z, Azman MY. Severe maternal morbidity and near misses in tertiary hospitals, Kelantan, Malaysia: a cross-sectional study. *BMC public health.* 2016;16(1):229.
42. New York City Department of Health and Mental Hygiene. *Severe Maternal Morbidity in New York City, 2008-2012.* New York, NY: New York City Department of Health and Mental Hygiene Bureau of Maternal, Infant and Reproductive Health; 2016.
43. Lydon-Rochelle M, Holt VL, Martin DP, Easterling TR. Association between method of delivery and maternal rehospitalization. *Jama.* 2000;283(18):2411-2416.
44. Meikle SF, Lyons E, Hulac P, Orleans M. Rehospitalizations and outpatient contacts of mothers and neonates after hospital discharge after vaginal delivery. *American journal of obstetrics and gynecology.* 1998;179(1):166-171.
45. Clapp MA, Little SE, Zheng J, Robinson JN. A multi-state analysis of postpartum readmissions in the United States. *American journal of obstetrics and gynecology.* 2016;215(1):113. e111-113. e110.
46. Liu S, Heaman M, Kramer MS, et al. Length of hospital stay, obstetric conditions at childbirth, and maternal readmission: a population-based cohort study. *American journal of obstetrics and gynecology.* 2002;187(3):681-687.
47. Ellis R, Whittington D. *Quality assurance for health care: a handbook.* London: Edward Arnold; 1993.
48. Jennings B, Baily MA, Bottrell M, Lynn J. *Health care quality inprovement : ethical and regulatory issues.* New York, United States: The Hastings Center; 2007.
49. Donabedian A. *Exploration in quality assessment and monitoring: The definition of quality and approaches to its assessment.* Ann Arbor, Michigan, United Sates: Health Administration Press; 1980.
50. Roemer MI, Montoya-Aguilar C, Organization WH. *Quality assessment and assurance in primary health care.* Geneva, Switzerland: World Health Organisation;1988.
51. Institute of Medicine. *Medicare: A strategy for quality assurance.* Washington DC, United States: National Academy Press; 1990.
52. Wilson L, Goldsmith P. *Quality and its measurements.* Sydney, Australia: McGraw-Hill; 1995.

연세대학교
YONSEI UNIVERSITY

53. Kelley E, Hurst J. *Health Care Quality Indicators Project: Conceptual Framework Paper.* Paris: OECD Publishing;2006.
54. Leatherman ST, Sutherland K. *The quest for quality: A chartbook on quality of care in the UK.* United Kingdom: Radcliffe Publishing; 2005.
55. WHO. *Quality of care : a process for making strategic choices in health systems.* Geneva : World Health Organization: WHO Press; 2006.
56. Donabedian A. The quality of medical care. *Science.* 1978;200(4344):856-864.
57. Donabedian A. Evaluating the quality of medical care. *The Milbank memorial fund quarterly.* 1966;44(3):166-206.
58. Institute of Medicine. *Envisioning the National Health Care Quality Report.* Washington DC, United States: National Academies Press; 2001.
59. Institute of Medicine. *Crossing the Quality Chasm: A New Health System for the 21st Century.* Washington DC, United States: National Academy Press; 2001a.
60. Ovretveit J. *Health Service Quality: An Introduction to Quality Methods for Health Services.* Blackwell Scientific Publications; 1992.
61. Maxwell RJ. Dimensions of quality revisited: from thought to action. *Quality in health care.* 1992;1(3):171-177.
62. Raven JH, Tolhurst RJ, Tang S, Van Den Broek N. What is quality in maternal and neonatal health care? *Midwifery.* 2012;28(5):e676-e683.
63. Austin A, Langer A, Salam RA, Lassi ZS, Das JK, Bhutta ZA. Approaches to improve the quality of maternal and newborn health care: an overview of the evidence. *Reproductive health.* 2014;11(2):S1.
64. Raven J, Hofman J, Adegoke A, Van Den Broek N. Methodology and tools for quality improvement in maternal and newborn health care. *International Journal of Gynecology & Obstetrics.* 2011;114(1):4-9.
65. WHO. *Standards for improving quality of maternal and newborn care in health facilities.* Geneva, Switzerland: WHO Press; 2016.
66. Tunçalp Ö, Were W, MacLennan C, et al. Quality of care for pregnant women and newborns—the WHO vision. *BJOG: an international journal of obstetrics & gynaecology.* 2015;122(8):1045-1049.
67. Bohren MA, Hunter EC, Munthe-Kaas HM, Souza JP, Vogel JP, Gülmezoglu AM. Facilitators and barriers to facility-based delivery in low-and middle-income countries: a qualitative evidence synthesis. *Reproductive health.* 2014;11(1):71.
68. Hulton L, Matthews Z, Stones RW. *A framework for the evaluation of quality of care in maternity services.* University of Southampton: Southampton, United Kingdom; 2000.
69. Pittrof R, Campbell OM, Filippi VG. What is quality in maternity care? An international perspective. *Acta obstetricia et gynecologica Scandinavica.* 2002;81(4):277-283.
70. Engender Health. *COPE for maternal Health Sevices: A process and Tools for Improving the Quality of Maternal Health Services.* New York, United States: Engender Health; 2001.
71. Donabedian A. The quality of care: how can it be assessed? *Jama.* 1988;260(12):1743-1748.
72. Renfrew MJ, McFadden A, Bastos MH, et al. Midwifery and quality care: findings from a new evidence-informed framework for maternal and newborn care. *The Lancet.* 2014;384(9948):1129-1145.
73. Callaghan WM, Grobman WA, Kilpatrick SJ, Main EK, D'Alton M. Facility-based identification of women with severe maternal morbidity: it is time to start. *Obstetrics and*

연세대학교
YONSEI UNIVERSITY

gynecology. 2014;123(5):978-981.
74. UN General Assembly. *United Nations Millennium Declaration, Resolution Adopted by the General Assembly, 18 September 2000, A/RES/55/2.* New York, United States: UN General Assembly;2000.
75. Ban K-m. *Global Strategy for Women's and Children's health.* New York, United States: United Nations 2010.
76. Centre for Maternal and Child Enquiries. Saving Mothers' Lives: reviewing maternal deaths to make motherhood safer: 2006–08. The Eighth Report on Confidential Enquiries into Maternal Deaths in the United Kingdom. . *BJOG: An International Journal of Obstetrics & Gynaecology.* 2011;118(Supp 1):1-203.
77. Schutte JM, Schuitemaker N, Van Roosmalen J, Steegers E. Substandard care in maternal mortality due to hypertensive disease in pregnancy in the Netherlands. *BJOG: An International Journal of Obstetrics & Gynaecology.* 2008;115(6):732-736.
78. D'alton ME. Where is the "M" in maternal–fetal medicine? *Obstetrics & Gynecology.* 2010;116(6):1401-1404.
79. Baskett TF. Epidemiology of obstetric critical care. *Best Practice & Research Clinical Obstetrics & Gynaecology.* 2008;22(5):763-774.
80. Bouvier-Colle MH, Mohangoo A, Gissler M, et al. What about the mothers? An analysis of maternal mortality and morbidity in perinatal health surveillance systems in Europe. *BJOG: An International Journal of Obstetrics & Gynaecology.* 2012;119(7):880-890.
81. Geller SE, Rosenberg D, Cox S, Brown M, Simonson L, Kilpatrick S. A scoring system identified near-miss maternal morbidity during pregnancy. *Journal of clinical epidemiology.* 2004;57(7):716-720.
82. Hankins GD, Clark SL, Pacheco LD, O'keeffe D, D'alton M, Saade GR. Maternal mortality, near misses, and severe morbidity: lowering rates through designated levels of maternity care. *Obstetrics & Gynecology.* 2012;120(4):929-934.
83. Kuklina EV, Meikle SF, Jamieson DJ, et al. Severe obstetric morbidity in the United States: 1998–2005. *Obstetrics and gynecology.* 2009;113(2 Pt 1):293-299.
84. Yasmeen S, Romano PS, Schembri ME, Keyzer JM, Gilbert WM. Accuracy of obstetric diagnoses and procedures in hospital discharge data. *American journal of obstetrics and gynecology.* 2006;194(4):992-1001.
85. Kilpatrick SJ, Berg C, Bernstein P, et al. Standardized severe maternal morbidity review: rationale and process. *Journal of Obstetric, Gynecologic, & Neonatal Nursing.* 2014;43(4):403-408.
86. You WB, Chandrasekaran S, Sullivan J, Grobman W. Validation of a scoring system to identify women with near-miss maternal morbidity. *American journal of perinatology.* 2013;30(01):021-024.
87. Main EK, Abreo A, McNulty J, et al. Measuring severe maternal morbidity: validation of potential measures. *American journal of obstetrics and gynecology.* 2016;214(5):643. e641-643. e610.
88. Ozimek JA, Eddins RM, Greene N, et al. Opportunities for improvement in care among women with severe maternal morbidity. *American journal of obstetrics and gynecology.* 2016;215(4):509. e501-509. e506.
89. Donabedian A. *An introduction to quality assurance in health care.* New York, NY: Oxford University Press; 2003.
90. Lee J, Lee JS, Park S-H, Shin SA, Kim K. Cohort profile: The national health insurance service–national sample cohort (NHIS-NSC), South Korea. *International journal of*

연세대학교
YONSEI UNIVERSITY

epidemiology. 2016:dyv319.
91. Health Insurance Review and Assessment Service. Healthcare Bigdata Hub. 2017; http://opendata.hira.or.kr/op/opc/olapOecdInfo.do. Accessed March 3, 2017.
92. Kim J, Im J, HY K. *Development of risk adjustment and prediction methods for care episodes using National Health Insurance database.* Seoul: Health Insurance Review and Assessment Service; 2007.
93. Zahr CA, Wardlaw TM. *Maternal mortality in 2000: estimates developed by WHO, UNICEF and UNFPA.* Geneva: World Health Organization; 2004.
94. Center for Disease Control and Prevention. Pregnancy Mortality Suveillance System. https://www.cdc.gov/reproductivehealth/maternalinfanthealth/pmss.html. Accessed 13 April, 2017.
95. Kotelchuck M. An evaluation of the Kessner adequacy of prenatal care index and a proposed adequacy of prenatal care utilization index. *American journal of public health.* 1994;84(9):1414-1420.
96. Palmer WL, Bottle A, Aylin P. Association between day of delivery and obstetric outcomes: observational study. *BMJ.* 2015;351:h5774.
97. Macfarlane A. Variations in number of births and perinatal mortality by day of week in England and Wales. *BMJ.* 1978;2(6153):1670-1673.
98. Mathers C. Births and perinatal deaths in Australia: variations by day of week. *Journal of Epidemiology and Community Health.* 1983;37(1):57-62.
99. Howell EA, Zeitlin J, Hebert PL, Balbierz A, Egorova N. Association between hospital-level obstetric quality indicators and maternal and neonatal morbidity. *JAMA.* 2014;312(15):1531-1541.
100. Zwart J, Richters J, Öry F, De Vries J, Bloemenkamp K, Van Roosmalen J. Severe maternal morbidity during pregnancy, delivery and puerperium in the Netherlands: a nationwide population-based study of 371 000 pregnancies. *BJOG: An International Journal of Obstetrics & Gynaecology.* 2008;115(7):842-850.
101. Kearns A, Caglia J, Hoope-Bender P, Langer A. Antenatal and postnatal care: a review of innovative models for improving availability, accessibility, acceptability and quality of services in low-resource settings. *BJOG: An International Journal of Obstetrics & Gynaecology.* 2016;123(4):540-548.
102. Hodgins S, D'Agostino A. The quality–coverage gap in antenatal care: toward better measurement of effective coverage. *Global Health: Science and Practice.* 2014;2(2):173-181.
103. Snowden JM, Kozhimannil KB, Muoto I, Caughey AB, McConnell KJ. A 'busy day'effect on perinatal complications of delivery on weekends: a retrospective cohort study. *BMJ Quality & Safety.* 2016:bmjqs-2016-005257.
104. Cram P, Hillis SL, Barnett M, Rosenthal GE. Effects of weekend admission and hospital teaching status on in-hospital mortality. *The American journal of medicine.* 2004;117(3):151-157.
105. Joseph K, Liu S, Rouleau J, et al. Severe maternal morbidity in Canada, 2003 to 2007: surveillance using routine hospitalization data and ICD-10CA codes. *Journal of Obstetrics and Gynaecology Canada.* 2010;32(9):837-846.
106. Lavecchia M, Sabbah M, Abenhaim HA. Effect of Planned Mode of Delivery in Women with Advanced Maternal Age. *Maternal and child health journal.* 2016;20(11):2318-2327.
107. Rizwan N, Abbasi RM, Mughal R. Maternal morbidity and perinatal outcome with twin pregnancy. *J Ayub Med Coll Abbottabad.* 2010;22(2):105-107.

연세대학교
YONSEI UNIVERSITY

108. Rocha Filho EA, Costa ML, Cecatti JG, et al. Contribution of antepartum and intrapartum hemorrhage to the burden of maternal near miss and death in a national surveillance study. *Acta obstetricia et gynecologica Scandinavica.* 2015;94(1):50-58.
109. Chen X-K, Wen SW, Fleming N, Demissie K, Rhoads GG, Walker M. Teenage pregnancy and adverse birth outcomes: a large population based retrospective cohort study. *International journal of epidemiology.* 2007;36(2):368-373.
110. Gortzak-Uzan L, Hallak M, Press F, Katz M, Shoham-Vardi I. Teenage pregnancy: risk factors for adverse perinatal outcome. *Journal of Maternal-Fetal Medicine.* 2001;10(6):393-397.
111. Bukulmez O, Deren O. Perinatal outcome in adolescent pregnancies: a case-control study from a Turkish university hospital. *European Journal of Obstetrics & Gynecology and Reproductive Biology.* 2000;88(2):207-212.
112. Lindquist A, Kurinczuk J, Redshaw M, Knight M. Experiences, utilisation and outcomes of maternity care in England among women from different socio-economic groups: findings from the 2010 National Maternity Survey. *BJOG: An International Journal of Obstetrics & Gynaecology.* 2015;122(12):1610-1617.
113. Yelland JS, Sutherland GA, Brown SJ. Women's experience of discrimination in Australian perinatal care: the double disadvantage of social adversity and unequal care. *Birth.* 2012;39(3):211-220.

연세대학교
YONSEI UNIVERSITY

Appendix

연세대학교
YONSEI UNIVERSITY

Appendix 1. Severe maternal morbidity indicators and corresponding ICD-9 and ICD-10 code.

Severe Maternal Morbidity Indicator	ICD-9-CM Codes	ICD-10-CM Codes
1. Acute myocardial infarction	410.xx	I21, I22
2. Acute renal failure	584.x, 669.3x	N17, O90.4
3. Adult respiratory distress syndrome	518.5, 518.81, 518.82, 518.84,799.1	J80, J95, J96, R092
4. Amniotic fluid embolism	673.1x	O88.1
5. Aneurysm	441.xx	I71, I79.0
6. Cardiac arrest/ventricular fibrillation	427.41, 427.42, 427.5	I46, I49.0
7. Disseminated intravascular coagulation	286.6, 286.9, 666.3x	D65, D68.8, D68.9, O72.3
8. Eclampsia	642.6x	O15
9. Heart failure during procedure or surgery	669.4x, 997.1	I971
10. Internal injuries of thorax, abdomen, and pelvis	860.xx—869.xx	S26, S27, S36, S37
11. Intracranial injuries	800.xx, 801.xx, 803.xx, 804.xx, 851.xx-854.xx	S06
12. Puerperal cerebrovascular disorders	430, 431, 432.x, 433.xx, 434.xx, 436, 437.x, 671.5x, 674.0x, 997.2, 999.2	I60, I61, I62, I63, I65, I66, I67, I68, O22.5, O87.3, I97.8
13. Pulmonary edema	428.1, 518.4	J81, I50
14. Severe anesthesia complications	668.0x, 668.1x, 668.2x	O74, O89
15. Sepsis	038.xx, 995.91, 995.92	O85, T80.2, T80.4, R65.1, A40, A41, A32.7
16. Shock	669.1x, 785.5x, 995.0, 995.4, 998.0	O751, R57, R65.2, T78.2, T81.1, T88.2, T88.6
17. Sickle cell anemia with crisis	282.62, 282.64, 282.69	D57
18. Thrombotic embolism	415.1x, 673.0x, 673.2x, 673.3x, 673.8x	I26, O88
19. Blood transfusion	99.0x	NA
20. Cardio monitoring	89.6x	NA
21. Conversion of cardiac rhythm	99.6x	NA
22. Hysterectomy	68.3x-68.9	NA
23. Operations on heart and pericardium	35.xx, 36.xx, 37.xx, 39.xx	NA
24. Temporary tracheostomy	31.1	NA
25. Ventilation	93.90, 96.01-96.05, 96.7x	NA

연세대학교
YONSEI UNIVERSITY

Appendix 2. Three factor health services index controlled for gestation and based on number of prenatal visits, interval to first prenatal visit, and type of hospital service.

Medical Care Index	Gestation(Weeks)		Number of Prenatal Visits
Adequate[a]	13 or less	and	1 or more or not stated
	14-17	and	2 or more
	18-21	and	3 or more
	22-25	and	4 or more
	26-29	and	5 or more
	30-31	and	6 or more
	32-33	and	7 or more.
	34-35	and	8 or more
	36 or more	and	9 or more
Inadequate[b]	14-21	and	0 or not stated
	22-29	and	1 or less or not stated
	30-31	and	2 or less or not stated
	32-33	and	3 or less or not stated
	34 or more	and	4 or less or not stated
Intermediate	All combinations other than specified above		

* Additional number of prenatal visits:
[a] The first prenatal visit had to be first trimester(<13weeks)
[b] To start prenatal visit during the third trimester (>28weeks)

연세대학교
YONSEI UNIVERSITY

Appendix 3. List of comorbidities and complications during

Comorbidities	ICD-10 codes
Comorbidities during pregnancy	
Cardiac disease	I20, I25, I27, I34, I35, I36 , I37, I38, I39, I42, I44, I50
Renal disease	N02, N03, N04, N08, N11, N18, N19, N25, N26, N30
Musculoskeletal disease	M11, M42, M45, M46, M91, M92, M93
Digestive disorder	K50
Blood	D51, D52, D53, D55, D56, D57, D58, D59, D60, D61, D63, D64, D65, D66, D67, D68, D69, D70, D71, D72
Mental	F01, F02, F03, F04, F05, F06, F07, F10, F11, F12, F15, F19, F20, F22, F30, F32, F33, F41, F43, F45, F54, F60, F66, F70, F80, F81, F90, F91, F938, F98
CNS disease	G35, G36, G37, G40, G43, G80, G81, G82, G83
Rheumatic heart disease	I05, I06, I07, I08, I09
Lupus	M32
Collagen vascular disorder	M33, M34, M35
Rheumatoid arthritis	M05, M06, M08, M12
Diabetes	E10, E11
Diabetes complicating pregnancy	O24, O998
Obesity	O992, E660
Asthma/Chronic bronchitis	J41, J42, J44, J45

연세대학교
YONSEI UNIVERSITY

Appendix 4. The cumulative incidence for maternal mortality

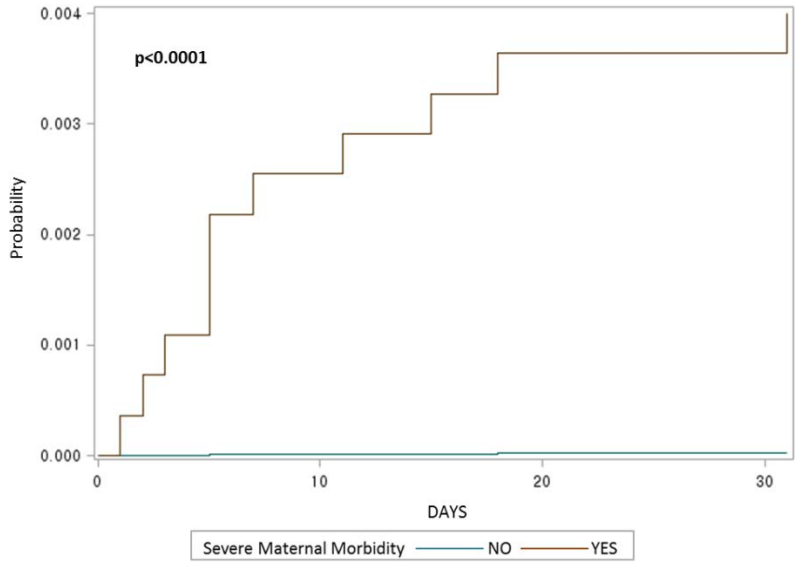

Figure A1. The cumulative incidence of maternal mortality within 6 weeks after delivery by SMM

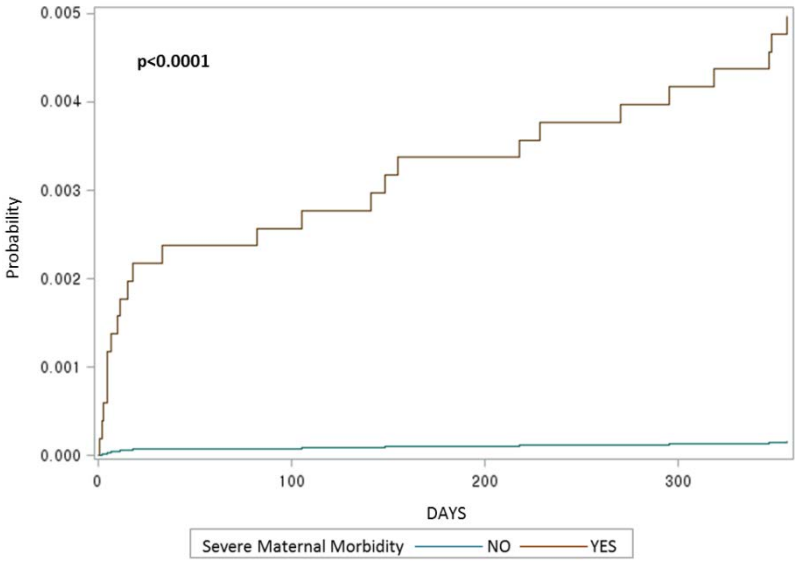

Figure A2. The cumulative incidence of maternal mortality within 1 year after delivery by SMM

연세대학교
YONSEI UNIVERSITY

Appendix 5. The relationship between severe maternal morbidity and maternal mortality within 6 weeks using Cox proportional hazard analysis

	Maternal mortality within 6 weeks					
	Total	**N**	**HR**	**95% CI**		**P-value**
Severe maternal morbidity						
No	89544	2	1.00			
Yes	2249	9	397.91	51.19	3093.02	<.0001
Adequacy of prenatal care						
Adequate	72814	8	1.00			
Intermediate	17110	3	1.48	0.18	11.84	0.7143
Inadequate	1869	0	-	-	-	
Access to labor or obstetrics facility						
Both of None	1597	0	-	-	-	
Only obstetrics	1407	1	1.01	0.07	13.99	0.9928
Both	88789	10	1.00			
Day/time of delivery						
Weekday daytime	80027	6	1.00			
Weekday nighttime	8686	4	9.60	2.57	35.90	0.0008
Weekend or holiday	3080	1	7.01	0.81	60.71	0.0769
Individual factors						
Maternal age (years)						
15-19	310	0	-	-	-	
20-24	4213	0	-	-	-	
25-29	28660	2	1.00			
30-34	43210	6	0.80	0.08	7.71	0.8497
35-39	13536	2	0.81	0.09	7.33	0.8521
40-44	1797	1	2.25	0.11	45.96	0.5978
45-49	67	0	-	-	-	
Income level						
1Q	8630	3	1.00			
2Q	13434	1	0.40	0.04	4.39	0.4511
3Q	24025	2	0.25	0.04	1.71	0.1562
4Q	29904	5	0.58	0.10	3.26	0.5369
5Q	15800	0	-	-	-	
Type of insurance						
Self-employed insured	26786	4	3.31	0.73	14.99	0.1200
Employee insured	64712	7	1.00			
Medical aid	295	0	-	-	-	
Residential area						
Metropolitan (Seoul)	18374	4	1.00			
City	23018	1	0.22	0.04	1.39	0.1081
Rural	50401	6	1.36	0.19	9.83	0.7602
Working status						
Work	25524	5	1.00			
Not work	66243	6	1.09	0.47	2.53	0.8486

연세대학교
YONSEI UNIVERSITY

Appendix 5. The relationship among severe maternal morbidity and maternal mortality within 6 weeks using Cox proportional hazard analysis *(continued)*

	Maternal mortality within 6 weeks					
	Total	**N**	**HR**	**95% CI**		**P-value**
Obstetric factors						
Mode of delivery						
Spontaneous vaginal delivery	32560	4	5.87	0.71	48.31	0.1001
Instrumental delivery	24924	1	0.61	0.13	2.86	0.5318
Cesarean section delivery	34309	6	1.00			
Parity						
1 (Nulliparous)	61274	6	2.62	0.34	20.00	0.3528
2	27050	4	1.00			
3+	3469	1	9.44	0.61	145.62	0.1079
Twin birth status						
Singleton	90466	11	1.00			
Twin	1327	1	-	-	-	
Preterm birth						
≥ 37 weeks	6252	6	31.54	5.16	192.71	0.0002
< 37 weeks	61937	4	1.00			
Length of stay for delivery hospitalization	23604	1	0.15	0.02	1.19	0.0730
Short-term						
Normal	90854	11	1.00			
Long-term	939	0	-	-	-	
Comorbidities during pregnancy						
0	90736	7	1.00			
1+	1057	4	22.29	2.70	184.07	0.0040
Hospital factors						
Type of hospital						
Clinic (<30 beds)	20474	3	0.61	0.17	2.23	0.4531
Clinic (30≤beds<100)	22231	2	0.63	0.03	13.97	0.7720
Hospital (30≤beds<100)	15932	2	1.00			
Hospital (100≤beds<500)	16596	0	-	-	-	
General hospital (<500 beds)	6159	2	0.40	0.07	2.40	0.3161
General hospital (≥500 beds)	10401	2	0.11	0.01	2.63	0.1724
Hospital ownership						
Public	396	0	-	-	-	
Private, for -profit	91397	11	1.00			
Hospital location						
Urban	45533	7	1.00			
Rural	46260	4	0.39	0.04	3.93	0.4251

연세대학교
YONSEI UNIVERSITY

Appendix 5. The relationship among severe maternal morbidity and maternal mortality within 6 weeks using Cox proportional hazard analysis *(continued)*

	Maternal mortality within 6 weeks					
	Total	**N**	**HR**	**95% CI**		**P-value**
Hospital region						
Capital area	45606	8	1.00			
Gangwon region	2265	0	-	-	-	
Chungcheong region	9235	2	1.49	0.18	12.29	0.7114
Gyeongsang region	23476	1	0.54	0.01	27.06	0.7601
Jeolla region	10012	0	-	-	-	
Jeju region	1199	0	-	-	-	
Year						
2003	8526	1	1.00			
2004	8477	0	-	-	-	
2005	8194	2	3.41	0.55	21.12	0.1873
2006	8219	1	0.74	0.03	20.09	0.8596
2007	9021	2	2.16	0.31	15.19	0.4384
2008	8283	0	-	-	-	
2009	7571	2	0.65	0.05	9.38	0.7536
2010	7975	1	0.23	0.01	4.31	0.3247
2011	8654	2	1.53	0.12	18.98	0.7414
2012	8875	0	-	-	-	
2013	7998	0	-	-	-	

HR: hazard ratio
Adjusted for all covariates

연세대학교
YONSEI UNIVERSITY

Appendix 6. The relationship between severe maternal morbidity and maternal mortality within 1 year using Cox proportional hazard analysis

	Maternal mortality within 1 year					
	Total	**N**	**HR**	**95% CI**		**P-value**
Severe maternal morbidity						
No	89544	14	1.00			
Yes	2249	11	33.90	13.60	84.51	<.0001
Adequacy of prenatal care						
Adequate	72814	17	1.00			
Intermediate	17110	8	1.93	0.79	4.71	0.1486
Inadequate	1869	0	-	-	-	
Access to labor or obstetrics facility						
Both of None	1597	0	-	-	-	
Only obstetrics	1407	1	2.15	0.20	23.48	0.5316
Both	88789	24	1.00			
Day/time of delivery						
Weekday daytime	80027	18	1.00			
Weekday nighttime	8686	6	3.54	1.07	11.75	0.0389
Weekend or holiday	3080	1	1.29	0.15	11.41	0.8177
Individual factors						
Maternal age (years)						
15-19	310	0	-	-	-	
20-24	4213	1	1.81	0.18	18.39	0.6146
25-29	28660	3	1.00			
30-34	43210	16	3.38	0.98	11.66	0.0542
35-39	13536	3	1.68	0.34	8.28	0.5229
40-44	1797	2	6.04	0.72	50.86	0.0978
45-49	67	0	-	-	-	
Income level						
1Q	8630	4	1.00			
2Q	13434	2	0.28	0.05	1.49	0.1368
3Q	24025	6	0.50	0.16	1.61	0.2452
4Q	29904	12	0.77	0.26	2.35	0.6514
5Q	15800	1	0.11	0.01	0.85	0.0342
Type of insurance						
Self-employed insured	26786	12	2.06	0.94	4.51	0.0720
Employee insured	64712	13	1.00			
Medical aid	295	0	-	-	-	
Residential area						
Metropolitan (Seoul)	18374	7	1.00			
City	23018	5	0.45	0.10	2.08	0.3058
Rural	50401	13	0.67	0.22	2.02	0.4734
Working status						
Work	25524	5	1.00			
Not work	66243	20	1.91	0.82	4.44	0.1356

연세대학교
YONSEI UNIVERSITY

Appendix 6. The relationship between severe maternal morbidity and maternal mortality within 1 year using Cox proportional hazard analysis *(continued)*

	Maternal mortality within 1 year					
	Total	**N**	**HR**	**95% CI**		**P-value**
Obstetric factors						
Mode of delivery						
Spontaneous vaginal delivery	32560	9	1.64	0.63	4.25	0.3068
Instrumental delivery	24924	4	1.05	0.36	3.10	0.9251
Cesarean section delivery	34309	12	1.00			
Parity						
1 (Nulliparous)	61274	18	1.48	0.50	4.37	0.7436
2	27050	6	1.00			
3+	3469	1	1.05	0.12	9.26	0.9659
Twin birth status						
Singleton	90466	25	1.00			
Twin	1327	0	-	-	-	
Preterm birth						
≥ 37 weeks	6252	8	9.86	3.57	27.25	<.0001
< 37 weeks	61937	11	1.00			
Length of stay for delivery hospitalization	23604	6	0.74	0.25	2.22	0.5897
Short-term						
Normal	90854	25	1.00			
Long-term	939	0	-	-	-	
Comorbidities during pregnancy						
0	90736	21	1.00			
1+	1057	4	7.84	1.97	31.24	0.0035
Hospital factors						
Type of hospital						
Clinic (<30 beds)	20474	6	1.95	0.47	8.04	0.3565
Clinic (30≤beds<100)	22231	7	2.45	0.59	10.20	0.2186
Hospital (30≤beds<100)	15932	2	1.00			
Hospital (100≤beds<500)	16596	3	1.48	0.28	7.70	0.6447
General hospital (<500 beds)	6159	2	1.78	0.21	14.94	0.5974
General hospital (≥500 beds)	10401	5	0.77	0.10	6.06	0.8070
Hospital ownership						
Public	396	0	-	-	-	
Private, for -profit	91397	25	1.00			
Hospital location						
Urban	45533	14	1.00			
Rural	46260	11	0.68	0.21	2.18	0.5153

연세대학교
YONSEI UNIVERSITY

Appendix 6. The relationship between severe maternal morbidity and maternal mortality within 1 year using Cox proportional hazard analysis *(continued)*

	Maternal mortality within 1 year					
	Total	**N**	**HR**	**95% CI**		**P-value**
Hospital region						
Capital area	45606	12	1.00			
Gangwon region	2265	1	2.53	0.32	20.26	0.3809
Chungcheong region	9235	2	0.75	0.14	4.01	0.7381
Gyeongsang region	23476	6	1.31	0.35	4.86	0.6838
Jeolla region	10012	4	2.26	0.62	8.17	0.2157
Jeju region	1199	0	-	-	-	
Year						
2003	8526	2	1.00			
2004	8477	2	1.18	0.16	8.58	0.8676
2005	8194	2	1.42	0.19	10.72	0.7344
2006	8219	3	1.86	0.26	13.46	0.5388
2007	9021	2	1.47	0.19	11.69	0.7140
2008	8283	3	2.56	0.33	19.99	0.3695
2009	7571	4	3.36	0.49	23.17	0.2191
2010	7975	2	1.16	0.12	11.01	0.8965
2011	8654	3	1.74	0.18	16.51	0.6315
2012	8875	2	1.33	0.12	14.68	0.8176
2013	7998	0	-	-	-	

HR: hazard ratio
Adjusted for all covariates

연세대학교
YONSEI UNIVERSITY

국문초록

의료의 질 향상이 모성 건강 결과에 미치는 영향
- 적합한 산전관리, 분만시간, 분만기관 접근성과 심각한 모성질환 지표 중심으로

연세대학교 대학원 보건학과
남진영

배경: 한국은 대부분의 경우 의료기관에서 전문 분만인력과 함께 시설분만을 하지만, 모성사망비는 여전히 OECD 평균보다 높다. 모성사망의 대부분은 분만 중 또는 분만 이후 산욕기간에 발생하므로 산전 관리뿐만 아니라 분만과 이후 회복기간의 모성건강관리의 질 관리 및 향상은 불가피하다. 그러나 모성사망은 매우 드물게 발생하므로 모성사망을 대체할 수 있는 지표 개발이 필요하고, 이에 영향을 끼치는 위험요인들을 파악할 필요가 있다. 그러나 모성건강의 안전성에 대한 질 지표로 정의할 수 있는 분만 또는 분만입원 중 발생한 심각한 모성질환 (Severe maternal morbidity, SMM)에 대한 한국의 연구는 미흡한 상태이다.

목적: 이 연구는 의료의 질 관리 구성요소인 분만기관에 대한 접근성, 분만시간에 대한 적시성, 산전관리에 대한 효과성과 개인적 특성, 산과적 특성, 분만기관적 특성이 심각한 모성질환과 관련이 있는지 알아보고, 심각한 모성질환이 산욕기 재입원의 위험과 연관이 있는지 알아보고자 한다.

연세대학교
YONSEI UNIVERSITY

방법: 이 연구는 2003년부터 2013년까지 국민건강보험공단 표본코호트를 이용하여 총 91,767건의 분만을 추출하였다. 심각한 모성질환은 CDC(Center for Disease Control and Prevention)의 알고리즘을 사용하여 분만 또는 분만입원 기간 동안 발생한 심각한 모성 질환을 진단코드와 행위코드로 정의하였다. 이항 분포 및 일반화된 추정 방정식 모형(Generalized estimating equation)을 사용하여 심각한 모성질환과 분만 여성의 개인적, 산과적 특성과의 관련성을 측정하였고, 콕스 비례위험 모형(Cox proportional hazard model)을 사용하여 심각한 모성질환과 산욕기 재입원의 위험을 측정하였다.

결과: 91,767건의 분만 중 2,248(2.45%)건의 분만에서 심각한 모성질환이 있었다. 심각한 모성질환 중 수혈은 약 60%로 가장 빈도가 높은 지표였다. 심각한 모성질환은 부적절한 산전관리를 한 여성이 적절한 산전관리를 한 여성보다 1.39배 높았고 (Odds Ratio (OR) 1.39, 95% CI 1.08-1.79), 주중 밤에 분만한 여성과 주말 또는 공휴일에 분만한 여성은 주중 낮에 분만한 여성보다 각각 1.18배, 1.7배 높은 심각한 모성질환이 나타났다 (OR 1.18, 95% CI 1.02-1.38, OR 1.70, 95% CI 1.37-2.11). 분만기관에 대한 접근성과 심각한 모성질환의 관련성은 통계적으로 유의하지 않았다. 또한 산모의 나이는 J-모양을 나타내며 심각한 모성질환 위험과 통계적으로 유의한 관련성이 있었고, 소득이 매우 낮은 경우, 제왕절개 분만을 한 경우, 초산인 경우, 다태아인 경우 심각한 모성질환 위험이 더 높게 나타났다. 심각한 모성질환과 산욕기 재입원의 관련성 연구에서 심각한 모성질환이 발생한 여성은 재입원할 위험이 발생하지 않은 여성보다 약 2.3배 더 높게 나타났다 (Hazard Ratio 2.29, 95% CI 1.70-3.10).

결론: 적절한 산전관리는 분만 입원 중 발생하는 심각한 모성질환과 관련이 있었고, 밤 분만 및 주말 분만은 심각한 모성질환의 위험과 높은 관련이

연세대학교
YONSEI UNIVERSITY

있었다. 또한 심각한 모성질환을 가진 여성은 재입원할 위험이 높았다. 따라서 분만 및 산욕기 동안 심각한 모성질환을 예방할 수 있도록 임신기간 동안 시기적절하고 적합한 산전 관리 방문 횟수를 측정하고 모니터링 할 수 있는 질 지표 개발이 필요하고, 적절한 인적자원과 분만시설을 취약 지역과 시간에 배치하여 분만 및 산욕기 질 관리가 향상될 수 있도록 정책적으로 지원해야 할 것이다.

핵심어 : 분만, 산욕기, 심각한 모성질환, 모성건강의 질 관리, 산전관리, 주말 분만, 산욕기 재입원