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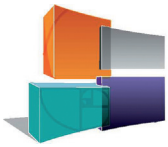

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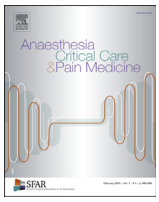

Original Article

Retrospective cohort study of decision-to-delivery interval and neonatal outcomes according to the type of anaesthesia for code-red emergency caesarean sections in a tertiary care obstetric unit in France☆

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ABSTRACT

Background: Non-elective caesarean sections may be classified using a three-colour coding system, from code-green caesarean section corresponding to non-urgent delivery (no maternal of foetal compromise) to code-red caesarean section corresponding to emergency caesarean section due to immediate life-threatening maternal or foetal situations. Decision-to-delivery interval ≤ 15 min has been advocated in France for code-red caesarean section. This retrospective cohort study aimed to assess the decision-to-delivery interval and the neonatal outcomes according to the anaesthetic technique performed for code red caesarean section in a French tertiary care obstetric unit.

Methods: All women undergoing code-red caesarean section between January 2013 and December 2015 were included. Demographic characteristics and anaesthetic, obstetrical and neonatal outcomes were collected from the patient's electronic medical records.

Results: Among 194 code-red caesarean sections analysed, 127 (65%) were performed under epidural anaesthesia and 67 (35%) under primary general anaesthesia. The median decision-to-delivery interval was 10 [8–12.5] min, and the interval was ≤ 15 min in 174 (90%) women. Effective epidural top-up and epidural top-up requiring supplemental sedation were associated with the shortest decision-to-delivery interval. Primary general anaesthesia was independently associated with depressed 5 minutes Apgar score.

Conclusion: The decision-to-delivery interval was ≤ 15 min in most women, suggesting that optimised organisation ensures short decision-to-delivery interval independently of the anaesthetic technique performed. As general anaesthesia was associated with worse neonatal outcomes, our results support the early insertion of an epidural catheter whenever there is any potential concern that an emergency caesarean section may be required.

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1. Introduction

The use of a four graded classification proposed by Lucas et al. is advocated in the United Kingdom (UK) for the timing of caesarean section: from category 1 (emergency caesarean section) to category 4 (elective caesarean section) [1]. For category-1 caesarean section, decision-to-delivery interval ≤ 30 minutes is used to measure the overall performance of an obstetric unit [2]. Non-elective caesarean sections can also be classified using a

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three-colour coding system facilitating the communication of the degree of urgency between members of the obstetrical team [3,4]: code-red caesarean section corresponds to emergency caesarean section due to immediate life-threatening maternal or foetal situations, code-orange caesarean section corresponds to urgent case related to maternal or foetal compromise which is not immediately life-threatening, and code-green caesarean section corresponds to caesarean section requiring non-urgent delivery (no maternal or foetal compromise). Red-code indications correspond to category 1 in the Lucas et al. classification [1], for which a decision-to-delivery interval $\leq$ 15 min has been advocated in France in order to minimise the risk of cerebral damage related to prolonged foetal anoxia [4]. Hence, for these cases, the anaesthetic technique should ensure fast and safe effective anaesthesia.

General anaesthesia allows short time interval between start of anaesthesia and skin incision. However, despite the decrease in maternal morbidity and mortality related to anaesthesia over the last 30 years [5,6], this technique remains associated with several serious potential sides effect, such as pulmonary aspiration, intraoperative awareness, theoretical increased risk of postpartum haemorrhage, and worse umbilical arterial pH and base excess [6–10]. Neuraxial anaesthesia contributes to avoid complications related to general anaesthesia and is therefore recommended by the UK National Institute for Health and Clinical Excellence [2,11], though it has been associated with increased decision-to-delivery-interval in comparison with general anaesthesia [10,12–15]. Neuraxial anaesthesia can be achieved either by performing rapid spinal anaesthesia or through the extension of a well functional labour epidural analgesia, the most used technique in France where epidural analgesia is performed in about 80% of the parturients [16]. However, several previous studies have reported that the goal of decision-to-delivery interval $\leq$ 30 min is difficult to achieve in clinical practice. The decision-to-delivery interval includes the time to establish anaesthesia; therefore, one crucial point is the time where epidural top-up is started once the decision of caesarean section is made. In our hospital, team communication and organisation have been modified to optimise epidural top-up injection when it is performed in the delivery room.

The main aim of this retrospective study was to assess whether this organisation privileging a large use of an epidural top-up for code-red caesarean section allows to comply with the target decision-to-delivery interval of 15 minutes (corresponding to our local goal [4]) and of 30 min (as currently advocated in the UK to test the efficiency of the whole delivery team [2]). The second aim of this study was to assess neonatal outcomes after code-red caesarean section and to define independent risk factors for Apgar score $<$ 7 at 5 minutes that is predictive of increased risk of neonatal and infant death [17,18].

2. Methods

2.1. Study design

We performed a retrospective single-centre study in our university teaching hospital (4300 deliveries/year). The study protocol was approved (L15-73) by the local ethics committee (Comité pour la Protection des Personnes Sud-Est IV, Centre Léon Bérard, Lyon, Chairperson Dr D. Perol) on 29 April 2015.

Code-red caesarean sections performed over 3 years (January 2013 to December 2015) were retrospectively included. Code-red caesarean section is indicated in case of immediate life-threatening maternal or foetal situations such as suspicion of placental abruption, severe haemorrhage, eclampsia, uterine rupture, acute severe foetal bradycardia, failure of instrumental extraction with foetal distress, or cord prolapse [3,4].

2.2. Local medical practice and organisation

In our obstetric delivery suite, an operating room dedicated to caesarean sections is available at all times of the day and is located 20 meters from the delivery room. Complete pack of sterile instruments is always available in the operating room. At least one senior obstetrician and one senior anaesthetist, both dedicated to the delivery room and the obstetrical operating room, are on site 24 hours a day. Instrumental deliveries are performed in the delivery room. In case of decision of code-red caesarean section, the obstetrician presses an emergency call button alerting immediately and simultaneously the attending nurse and physician anaesthetists, the neonatologist and the midwives. A procedure has been set up 10 years ago (at inauguration of our hospital) and describes that transfer of the parturient to the operating room should involve one attending midwife and another caregiver.

The epidural top-up is performed whenever pain relief during labour has been achieved by a well-effective epidural analgesia (verbal pain score $\leq$ 2/10 without any supplementation nor any requirement of analgesic top-up during the last hour, and bilateral sensory level determined by cold at least higher than L1), using ropivacaine 1 mg.mL^{-1} and sufentanil 0.5 μg.mL^{-1} administered using patient-controlled epidural boluses with continuous epidural infusion; otherwise, primary general anaesthesia is performed for code-red caesarean sections. Spinal anaesthesia is exceptionally performed in our centre for code-red caesarean section, since this technique has been associated with the most prolonged decision-to-delivery interval and may not ensure decision-to-delivery interval $\leq$ 15 min [10,12,14,19,20]. Epidural top-up is achieved by the immediate epidural injection of 15 to 20 mL of lidocaine 20 mg.mL^{-1} with adrenaline or of ropivacaine 7.5 mg.mL^{-1} (at the discretion of the attending anaesthetist), with or without sufentanil 10 μg (at the discretion of the attending anaesthetist), in the epidural catheter already in place [21]. This epidural extension is performed by the nurse anaesthetist in the delivery room before the parturient is transferred to the operating room. Maternal blood pressure and heart rate, and foetal heart rate, are monitored during epidural top-up, as soon as the mother arrives in the operating room; hence, maternal and foetal monitoring is skipped for only less than 1 minute, corresponding to the mother shift to the operating room. Skin incision is allowed once bilateral T6 sensory level determined by cold has been achieved.

2.3. Data collection

Women who delivered by code-red caesarean section were identified using the hospital birth register, and by making a computer query using the keyword "code-red caesarean section" in the computerised anaesthesia and obstetric files. Demographic characteristics and anaesthetic, obstetrical and neonatal outcomes came from both the electronic anaesthetic medical record (Diane®, BOW medical, Lille, France) and the electronic obstetrical medical record (Cristalnet® software, Hospices Civils de Lyon, France). Maternal age, American Society of Anesthesiologists (ASA) physical status, body mass index, parity, maternal medical history, diseases occurring during pregnancy, gestational age, indications for code-red caesarean section, anaesthetic technique performed and need for ephedrine or phenylephrine before cord clamping were collected for analysis. The decision-to-delivery interval and the operating room-to-delivery interval were calculated. In case of epidural anaesthesia, the decision-to-injection interval, the injec-

tion-to-incision interval and the need for supplemental intravenous sedation or conversion to general anaesthesia before cord clamp were also recorded. Birth weight, Apgar scores at 1, 5, and 10 min of life, arterial and venous umbilical cord pH, presence of meconium-stained amniotic fluid, need for paediatric rescue therapy, need for neonatal intensive care unit, and neonatal mortality (before day of life 28), were also recorded for analysis.

2.4. Statistical analysis

Statistical analysis was performed using MedCalc® version 12.1.4.0 for Windows (MedCalc Software, Ostend, Belgium). After a Kolmogorov-Smirnov test for normality of distribution of the data, data were expressed either as mean (SD) or median [interquartile range], as appropriate. They were compared using Student's t test or Mann-Whitney's U test or Kruskal-Wallis test followed by the Conover test for multiple comparisons, as appropriate. Categorical variables were described as number (percentage), and compared using χ^2 test or Fisher's exact test, followed by Marascuilo procedure, as appropriate. The 95% confidence interval of incidence data was calculated using the Wilson method with continuity correction. For each test, $P < 0.05$ was considered as statistically significant.

Several factors including diseases occurring during pregnancy, indication for caesarean section, birth weight, gestational age and type of anaesthesia, were tested to assess whether they were associated with Apgar score < 7 at 5 minutes. Univariate analysis was followed by multivariate logistic regression analysis producing odds ratios (OR) with 95% confidence interval. For construction of multivariable models, all variables associated ($P < 0.1$) with Apgar score < 7 at 5 minutes in univariable analysis were subjected to a stepwise logistic regression analysis. Multiple pregnancies were re-introduced so as to consider the outcome for each neonate separately. Potential confounding factors were eliminated if the P-value was > 0.1 but remained in the model if the P-value was < 0.05. The goodness of fit of the logistic regression for multivariate analysis was assessed using the Hosmer-Lemeshow test, and a receiver operating characteristic

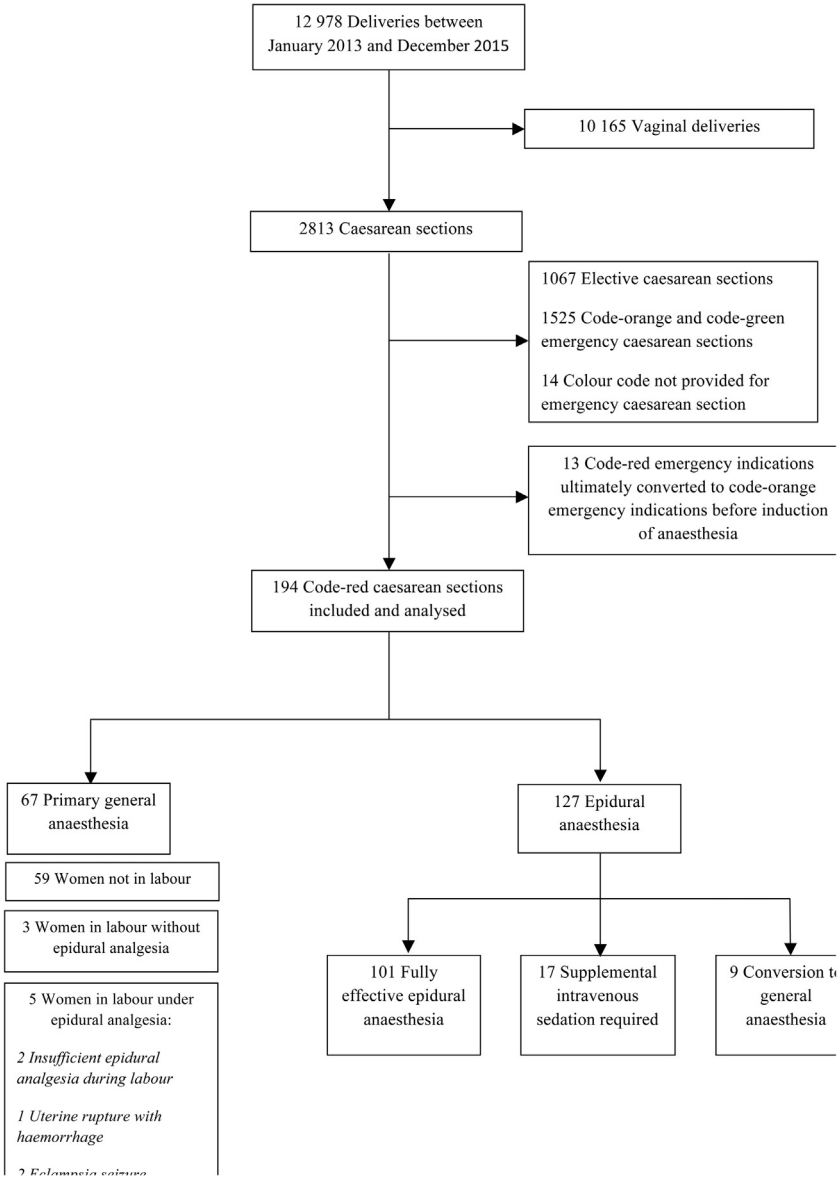

Fig. 1. Flow chart.

curve was used to assess the predictive value of the multivariate analysis.

3. Results

A total of 194 red caesarean sections for 208 childbirths, including 12 twin pregnancies and one triple pregnancy, were included and analysed (Fig. 1).

Primary general anaesthesia was performed for 67 (35%) caesarean sections, one of which for triple pregnancy, and seven for twin pregnancy. Primary general anaesthesia was mainly performed for code-red caesarean sections decided in women who were neither in labour nor physically present in the delivery room at the time of the decision of caesarean delivery ($n = 59$, 88% of primary general anaesthesia; Fig. 1). The hypnotic drugs used for general anaesthesia were propofol ($n = 38$; 57%), thiopental ($n = 20$; 30%), ketamine ($n = 6$; 9%) and combination of propofol/etomidate ($n = 3$; 4%). Succinylcholine was administered in 61 (91%) women and mivacurium was used in two (3%) women. All but two women did not receive any intravenous opioid before cord clamping. Sufentanil was the opioid administered in the two women receiving opioid intravenously during induction of anaesthesia.

Epidural top-up extension was performed for 127 (65%) caesarean sections, five of which for twin pregnancy. Lidocaine 20 mg.mL^{-1} with adrenaline was used in 112 (88%) cases (median volume: 12 [10–15] mL), and ropivacaine 7.5 mg.mL^{-1} was used in 15 women (median volume: 12 [11–15] mL). Sufentanil 10 μg was administered in 45 women in addition to the local anaesthetic solution for epidural top-up. The rate of fully effective epidural top-up (requiring neither supplemental sedation nor general anaesthesia) was 80% (95% confidence interval: 72.6 to 87.4%), while the rate of complete failure of epidural top-up (converted to general anaesthesia) was 7% (95% confidence interval: 2.2 to 11.8%; Fig. 1). The drugs administered in case of supplemental intravenous sedation were alfentanil ($n = 8$, 500 [150–500] μg), midazolam ($n = 5$, 2 [1–2] mg), ketamine ($n = 5$, 20 [10–50] mg), propofol ($n = 3$, 50 [50–100] mg) and sufentanil ($n = 1$, 5 μg).

The characteristics of caesarean sections performed under epidural anaesthesia and primary general anaesthesia are presented in Table 1.

The overall median decision-to delivery interval was 10 [8–12.5] min. Code-red caesarean sections were performed in less than 15 min after the decision in 174 (89.7%) women, and the decision-to-delivery interval, was less than 30 min in 193 (99.5%) women. Effective epidural top-up was associated with significantly shorter decision-to-delivery interval in comparison with general anaesthesia and failed epidural top-up requiring general anaesthesia (Table 2). Nevertheless, the rate of decision-to-delivery interval > 15 min did not significantly differ according to the type of anaesthesia (Table 2), and the operating room-to-delivery interval did not significantly differ according to the type of anaesthesia performed (Table 2).

General anaesthesia was associated with decreased Apgar scores at 1, 5, and 10 min (Table 3). Primary general anaesthesia was significantly associated with increased rate of Apgar score < 7 at 1, 5 and 10 minutes compared to fully effective epidural anaesthesia and epidural anaesthesia requiring supplemental intravenous sedation. General anaesthesia was also associated with significantly more frequent respiratory interventions (manual ventilation and tracheal intubation of the newborn), more frequent transfer to neonatal intensive care unit and increased neonatal mortality (Table 3).

Apgar score < 7 at 5 minutes was associated with significantly increased rates of primary general anaesthesia, placental abruption, preeclampsia and eclampsia, and significantly decreased rates of acute severe foetal bradycardia and fully effective epidural anaesthesia, in univariate analysis (Table 4). Decision-to-delivery interval was significantly longer, and birth weight and gestational age were significantly lower, in neonates with Apgar score < 7 at 5 minutes, in univariate analysis (Table 4). These factors, as well as

Table 1
Characteristics of women who underwent caesarean sections performed under primary general anaesthesia or epidural anaesthesia.

Variable	Primary general anaesthesia ($n = 67$)	Epidural anaesthesia ($n = 127$)	P value
Maternal age (years)	31 ± 6	30 ± 5	0.57
Gestational age (weeks)	35 ± 7	39 ± 5	< 0.0001
Parity = 0	23 (34%)	71 (56%)	0.006
ASA physical status			0.69
1	52 (78%)	103 (81%)	
2	15 (22%)	24 (19%)	
BMI (kg.m^{-2})	26 [24–31]	28 [25–31]	0.12
Maternal medical history			
Chronic hypertension	2 (3%)	3 (2%)	1
Obesity	7 (10%)	14 (11%)	0.9
Previous caesarean section	14 (21%)	20 (16%)	0.49
Asthma	1 (1%)	11 (9%)	0.06
Non-monitored pregnancy	1 (1%)	3 (2%)	1
Pathology during pregnancy			
Premature rupture of the membranes	7 (10%)	9 (7%)	0.42
Gestational hypertension	1 (1%)	1 (1%)	1
Preeclampsia	5 (7%)	6 (5%)	0.65
Gestational diabetes	9 (13%)	13 (10%)	0.67
Indication for caesarean section			
Acute severe foetal bradycardia	28 (42%)	83 (65%)	0.003
Placental abruption	18 (27%)	3 (2%)	< 0.0001
Failure to instrumental extraction	0 (0%)	25 (20%)	< 0.0001
Cord prolapse	7 (10%)	10 (8%)	0.74
Uterine rupture	2 (3%)	3 (2%)	1
Eclampsia	3 (4%)	1 (1%)	0.12
Other	9 (13%)	2 (2%)	0.001
Vasopressive drug administered before cord clamp	1 (1%)	18 (14%)	0.004
Ephedrine	1 (1%)	15 (12%)	0.01
Phenylephrine	1 (1%)	6 (5%)	0.42

Data are expressed as mean ± standard deviation, number (%) or median [interquartile range]. ASA: American Society of Anesthesiologists, BMI: body mass index.

Table 2
Characteristics of the caesarean sections according to the type of anaesthetic technique.

	Primary general anaesthesia ($n = 67$)	Epidural anaesthesia converted to general anaesthesia ($n = 9$)	Epidural anaesthesia with supplemental intravenous sedation ($n = 17$)	Fully effective epidural anaesthesia ($n = 101$)	P value
Decision-to-delivery interval (min)	11 [10–14][a,b]	14 [9–15][a]	9 [8–12]	9 [8–11]	0.0003
Decision-to-delivery interval > 15 min	11 (16%)	2 (22%)	1(6%)	6 (6%)	0.06
Decision-to-injection interval (min)	NA	0 [0–4]	1 [0–2]	1 [0–2]	0.89
Injection-to-incision interval (min)	NA	5 [3–8]	5 [4–7]	6 [4–8]	0.49
Operating room-to-delivery interval (min)	6.5 [5–8]	7.5 [6–8]	7 [7–10]	7 [6–8]	0.11
Blood loss (mL)	400 [300–800]	400 [300–600]	500 [300–775]	400 [250–600]	0.36
Use of vasopressors	1 (1%)[a]	2 (22%)	2 (12%)	14 (14%)	0.03

Data are expressed as median [interquartile range] or number (percentage of patients).
[a] $P < 0.05$ in comparison with fully effective epidural anaesthesia.
[b] $P < 0.05$ in comparison with epidural anaesthesia with supplemental intravenous sedation.

Table 3
Neonatal data according to the type of maternal anaesthesia.

	Primary general anaesthesia ($n = 76$)	Epidural anaesthesia converted to general anaesthesia ($n = 9$)	Epidural anaesthesia with supplemental intravenous sedation ($n = 18$)	Fully effective epidural anaesthesia ($n = 105$)	P value
Meconium-stained amniotic fluid	6 (8%)[b]	2 (22%)	3 (17%)	26 (25%)	0.03
Apgar 1 min	5 [1–8][b,c]	5 [2–9][b]	9 [5–9]	9 [7–9]	< 0.0001
Apgar 1 min < 7	49 (64%)[b,c]	5 (56%)	5 (28%)	24 (23%)	< 0.0001
Apgar 5 min	8 [6–10][b,c]	8 [5–10][b,c]	10 [10–10]	10 [10–10]	< 0.0001
Apgar 5 min < 7	32 (42%)[b,c]	4 (44%)	0 (0%)	2 (2%)	< 0.0001
Apgar 10 min	9 [7–10][b,c]	9 [8–10] [b,c]	10 [10–10]	10 [10–10]	< 0.0001
Apgar 10 min < 7	14 (18%)[b,c]	2 (22%)	0 (0%)	0 (0%)	< 0.0001
Umbilical cord arterial pH[a]	7.21 [7.11–7.28]	7.21 [7.06–7.28]	7.14 [7.09–7.24]	7.20 [7.11–7.25]	0.65
Umbilical cord arterial pH < 7.20[a]	31 (46%)	3 (33%)	11 (65%)	51 (50%)	0.41
Umbilical cord venous pH[a]	7.25 [7.16–7.32]	7.24 [7.11–7.30]	7.20 [7.10–7.30]	7.25 [7.18–7.30]	0.6
Manual ventilation	48 (64%) [b,c]	5 (56%)	3 (17%)	18 (17%)	< 0.0001
Head oxygen bag	18 (24%)	4 (44%)	1 (6%)	11 (10%)	0.006
Intubation	21 (28%) [b,c,d]	0 (0%)	0 (0%)	0 (0%)	< 0.0001
Transfer to neonatal intensive care unit	44 (59%) [b,c]	2 (22%)	0 (0%)	9 (9%)	< 0.0001
Child death	7 (9%)	0 (0%)	0 (0%)	0 (0%)	0.006

Data are expressed as number (%) or median [interquartile range].
[a] Data available for 197 children (primary general anaesthesia: $n = 68$; fully effective epidural anaesthesia: $n = 103$; epidural anaesthesia with supplemental intravenous sedation: $n = 17$; epidural anaesthesia converted to general anaesthesia: $n = 9$).
[b] $P < 0.05$ in comparison with fully effective epidural anaesthesia.
[c] $P < 0.05$ in comparison with epidural anaesthesia with supplemental intravenous sedation.
[d] $P < 0.05$ in comparison with epidural anaesthesia converted to general anaesthesia.

epidural anaesthesia with supplemental intravenous sedation and failure to instrumental extraction, were all included in the logistic regression model for multivariate analysis (Table 4). According to multivariate analysis, general anaesthesia and decreased gestational age were independent risk factors of Apgar score < 7 at 5 minutes, with odds ratios of 7.8 (95% CI: 2.7–23) and 1.1 (95% CI: 1.05–1.25), respectively, while acute severe foetal bradycardia was negatively associated with Apgar score < 7 at 5 minutes, with odds ratio of 0.4 (95% CI: 0.2–0.8). The Hosmer-Lemeshow goodness-of-fit test for logistic regression was not significant ($P = 0.60$), and the area under the receiver operating characteristic curve for multivariate analysis was 0.87 (95% CI: 0.81–0.91).

4. Discussion

In our unit, the decision-to-delivery interval for code-red caesarean section, performed under epidural anaesthesia in around two thirds of women and under primary general anaesthesia in the remaining third, was ≤ 15 min in nearly 90% of the parturients, and was ≤ 30 min in nearly 100% of the parturients.

In particular, fully effective epidural anaesthesia ensured decision-to-delivery interval ≤ 15 min in more than 90% of women. Several previous studies have reported that neuraxial anaesthesia was associated with similar-to-prolonged decision-to-delivery interval compared to general anaesthesia. In fact, if spinal anaesthesia has been consistently associated with prolonged decision-to-delivery interval [10,12,14,19,20], an epidural top-up may ensure short decision-to-delivery interval [14], mainly depending on when the injection takes place. Mackenzie et al. reported significantly shorter decision-to-delivery interval for general anaesthesia compared to epidural anaesthesia [13], but in their study, the epidural catheter was not in place when the decision to perform emergent caesarean section was made. In our unit, epidural top-up was performed through an epidural catheter already sited and providing effective analgesia; the injection was performed quickly after the decision of caesarean section was announced, in the labour room, before the parturient was rapidly transferred to the operating room. Furthermore, the local anaesthetic solution providing the fastest onset of a block suitable to allow surgery was used in almost 90% of women [21]. Thus, in our unit, the induction sequence of epidural anaesthesia was optimal for most women, leading to rather short decision-to-delivery and operating room-to-delivery intervals. Our induction sequence could probably have been further optimised by adding bicarbonate to lidocaine in order to speed up the onset of epidural top-up [22] (chloroprocaine not available in France), a strategy that we did not adopt mainly because of the increased risk of medication error when mixing drugs in the setting of emergency caesarean section [23].

Table 4
Factors associated with Apgar score < 7 at 5 minutes.

	Apgar 5 min < 7 (n = 38)	Apgar 5 min ≥ 7 (n = 170)	P value
Gestational age (weeks)[a]	33 ± 6	39 ± 4	< 0.0001
Pathology during pregnancy			
Premature rupture of the membranes	6 (16%)	11 (6%)	0.12
Gestational hypertension	0 (0%)	2 (1%)	0.8
Preeclampsia[a]	5 (13%)	6 (4%)	0.045
Gestational diabetes	6 (14%)	16 (9%)	0.38
Indication for caesarean section			
Acute severe foetal bradycardia[a]	11 (29%)	106 (62%)	0.0004
Placental abruption[a]	11 (29%)	13 (8%)	0.0006
Failure to instrumental extraction[a]	1 (3%)	24 (14%)	0.09
Cord prolapse	4 (11%)	15 (9%)	0.98
Uterine rupture	5 (3%)	0 (0%)	0.63
Eclampsia[a]	3 (8%)	1 (0.5%)	0.021
Other[a]	8 (21%)	6 (4%)	0.0004
Decision-to-delivery interval (min)[a]	11 [9–15]	10 [8–12]	0.036
Vasopressive drug administered before cord clamp	9 (9%)	8 (8%)	0.91
Ephedrine	1 (3%)	15 (9%)	0.33
Phenylephrine	0 (0%)	7 (4%)	0.44
Type of maternal anaesthesia			
Fully effective epidural anaesthesia[a]	2 (5%)	103 (61%)	< 0.0001
Epidural anaesthesia with supplemental intravenous sedation[a]	0 (0%)	18 (11%)	0.075
Epidural anaesthesia converted to general anaesthesia	4 (10%)	5 (3%)	0.4
Primary general anaesthesia[a]	32 (84%)	44 (26%)	< 0.0001
Birth weight (grams)[a]	2053 ± 1041	2947 ± 837	< 0.0001
Second twin	8 (21%)	19 (11%)	0.17

Data are expressed as mean ± standard deviation, number (%), or as median [interquartile range]. ASA: American Society of Anesthesiologists; BMI: Body mass index.
[a] Variables tested in multivariate analysis.

In our cohort, less than 15% of parturients with epidural anaesthesia needed supplemental intravenous sedation and 7% needed fast conversion to general anaesthesia. The rate of supplemental intravenous sedation is in accordance with the rates previously reported by Sng et al. using either lidocaine 20 mg.mL^{-1} with adrenaline, ropivacaine 7.5 mg.mL^{-1} or levobupivacaine 5 mg.mL^{-1} for epidural top-up [24]. Furthermore, in our study, the rate of conversion to general anaesthesia was slightly lower than that reported in other studies where it ranged from 8 to 30% for category-1 caesarean sections [25–27]. Hence, the overall rate of failed epidural anaesthesias was only 20%, and was in line with the target for best practices defined by The Royal College of Anaesthetists [28]. As stated above, this may be mainly due to the use of an optimised induction sequence of epidural anaesthesia for most women in our unit. Furthermore, the practice of obstetrical anaesthesia by senior anaesthetists experienced in obstetrics and the hourly assessment of epidural analgesia efficacy throughout labour by a nurse anaesthetist dedicated to labour pain management may also have contributed to minimise the risk of failed epidural top-up and of conversion to general anaesthesia [29].

Herein, less than 40% of code-red caesarean sections were performed under general anaesthesia. This result is in accordance with the target stated by the Royal College of Anaesthetists which advocates a rate of less than 50% of general anaesthesia for category-1 caesarean sections [28]. Several authors reported a rate of primary general anaesthesia slightly more than 50% for category-1 caesarean sections [14,30], while others have reported low rates of general anaesthesia, being less than 20% [10,27]. However, these low rates of general anaesthesia were obtained because, in one study, category-2 caesarean sections were also included in the analysis [27], while in the other study, the most urgent indications of caesarean section were excluded from analysis [10]. The relatively low rate of general anaesthesia in our cohort is certainly related to the extensive use of epidural analgesia which was > 85% in our unit during the study period, which is a usual rate for a French level-3 obstetric unit [16]. Besides this strategy, the need for emergency caesarean section is predictable in most of the parturients allowing early insertion of epidural catheter to minimise the use of general anaesthesia, even in units with a low rate of epidural analgesia [31].

General anaesthesia was associated with the most prolonged decision-to-delivery interval, although the operating room-to-delivery interval did not significantly change according to the anaesthetic technique performed and the decision-to-delivery interval was ≤ 15 min for almost 90% of women operated under general anaesthesia. The decision-to-delivery interval includes the time that elapsed between the decision and the patient's arrival in the operating room [15]. In our unit, the large majority of red caesarean sections performed under general anaesthesia were decided in women not in labour and not located in the delivery room, but who had been hospitalised or admitted in the emergency unit of our hospital. Hence, the proportion of time required to transfer these women from the unit where they were hospitalised to the operating room in the calculation of the decision-to-delivery interval was increased, in comparison with the women who were already in the delivery room. In this subgroup of patients, the decision-to-delivery interval reflected more the structure of our institution than an effect related to the technique of anaesthesia in itself. Beside this, the short operating room-to-delivery interval when performing primary general anaesthesia led to decision-to-delivery interval ≤ 15 min for most women, illustrating that general anaesthesia is probably the most appropriate anaesthetic technique to be performed to comply with the objective of decision-to-delivery interval ≤ 15 min, when no effective epidural catheter is already in place [12,19].

Our results illustrate that our improved organisation ensured short decision-to-delivery interval in almost all women requiring code-red caesarean section, independently of the anaesthetic technique performed. In particular, the colour code for emergency caesarean section is well known by all team members, a simple measure that has significantly shortened the decision-to-delivery interval, and the use of which is recommended [2,4,32]. Another critical point to consider is the time needed to transfer the woman into the operating room [15]. A procedure has been established in

our unit, including the simultaneous call of all team members in case of code-red caesarean section, leading to particularly rapid transfer of the patient to the operating room. This organisation was facilitated by the presence of the medical staff on site 24 hours a day, and by favourable architectural aspects. Our results may certainly not be applicable in smaller maternity wards, where the medical staff has to be called while being at home, or working in an operating room located far from the delivery room [33]. Nevertheless, our results should encourage all maternity units to consider factors that could optimise their organisation and reduce the decision-to-delivery interval.

In the present study, decreased gestational age and primary general anaesthesia were both associated with Apgar score < 7 at 5 minutes, a predictor of increased risk of neonatal and infant death, mainly related to anoxia and infection [17]. It has been well established that low Apgar score at 5 minutes was more frequent in neonates delivered preterm [17] and that gestational age exhibits an inverse association with neonatal and infant mortality, while general anaesthesia has been reported to be an important risk factor of low Apgar scores and neonates' tracheal intubation requirement [10,20,34,35]. General anaesthesia may affect neonatal condition because of transient sedation of the neonate from the anaesthetic drugs. Furthermore, in our cohort, most women undergoing code-red caesarean section under primary general anaesthesia were not in labour and had discontinuous foetal heart rate monitoring. It can be hypothesised that the diagnosis of foetal distress was somewhat delayed, with more severe foetal condition in this subgroup of patients. To note, the decision-to-delivery interval was not an independent risk factor of Apgar score < 7 at 5 minutes. This result is not fully surprising, since decision-to-delivery intervals were ≤ 15 min in almost all women, with low inter-individual variability. In a larger cohort of parturients requiring category-1 caesarean section, Palmer et al. did not find any significant relationship between operating room-to-incision interval (ranging from 0 to 87 min) and depressed 5-min Apgar scores, while general anaesthesia was independently associated with worse neonatal outcomes [19]. Other authors have reported similar results [10]. Hence, although disputable because of the noticeable differences between women for whom primary general anaesthesia was performed, and those operated after an epidural top-up had been administered, as stressed above, these results may contribute to questioning the benefits of fast general anaesthesia, rather than regional anaesthesia, when no epidural catheter has been inserted for code-red caesarean section. The benefit/risk ratio between anaesthetic technique and decision-to-delivery interval on neonatal outcomes should be investigated further [10,19].

Conversion to general anaesthesia and supplemental intravenous sedation for insufficient quality of anaesthesia were not associated with worse neonatal outcome. The too small number of women, in whom conversion of epidural anaesthesia to general anaesthesia had been performed, however prevents from any definitive conclusion. Supplemental intravenous sedation consisted in the administration of low doses of anaesthetic agents with the aim of maintaining verbal contact with the mother during the procedure. Frölich et al. previously reported that a single intravenous dose of fentanyl and midazolam prior to spinal anaesthesia for elective caesarean section did not affect neonatal outcome in comparison with placebo [36]. Furthermore, it can also be assumed that foetal condition was not as severe as in women undergoing general anaesthesia in our cohort, since intravenous sedation was performed only in women with epidural analgesia, for whom code-red caesarean delivery was decided while they were in labour with continuous foetal heart rate monitoring, avoiding any delay in the diagnosis of foetal compromise.

The study has some limitations. The retrospective design of our study may be associated with possible imprecision due to retrospective data collection, in spite of the use of medical electronic records. A randomised prospective study comparing general anaesthesia with neuraxial anaesthesia for code-red caesarean section would probably not be feasible due to ethical considerations. Furthermore, our results reflect a local organisation and are dependent on the anaesthetic and obstetrical management performed in our obstetric unit, hence questioning their generalisability. In particular, the local goal of decision-to-delivery interval ≤ 15 min for every code-red caesarean section leads to perform general anaesthesia in case of ineffective epidural top-up as assessed once the woman has arrived in the operating room, without giving supplemental time to epidural anaesthesia to become fully effective. In the same way, no spinal anaesthesia was performed because this technique has been reported to be associated with increased decision-to-delivery interval in comparison with general anaesthesia and epidural top-up, and may therefore not be appropriate to ensure decision-to-delivery interval ≤ 15 min that corresponds to our local goal [4]. Nevertheless, regional anaesthesia, i.e., epidural and spinal anaesthesia should be preferred for caesarean section whenever possible, as stated by the current NICE guidelines [2,11], and in absence of epidural catheter, some anaesthetists may decide to attempt a fast spinal anaesthesia for category-1 caesarean section [10,14,19], without reporting worse neonatal outcomes. Lastly, the use of the decision-to-delivery interval to measure the overall performance of an obstetric unit has been questioned, as it does not precisely reflect the actual duration of foetal hypoxia, leading some authors to consider bradycardia-to-delivery interval ≤ 30 min as a more appropriate goal for foetal safety [37].

In conclusion, our results showed that epidural top-up in women in labour under effective epidural analgesia, and general anaesthesia in women for whom an epidural catheter had not been previously inserted, both ensured decision-to-delivery interval ≤ 15 min for most women requiring code-red caesarean section. Clear and well-known classification code for emergency caesarean section and reduced decision-to-operating room interval due to optimised local organisation allow short decision-to-delivery interval. Our results also showed that neonatal outcomes were better when epidural anaesthesia technique was performed, in comparison with general anaesthesia. These results support the early insertion of an epidural catheter in case of labour dystocia or other foreseeable obstetrical complication that may lead to perform emergency caesarean section, to allow fast epidural topping-up.

Human and animal rights

The authors declare that the work described has been carried out in accordance with the Declaration of Helsinki of the World Medical Association revised in 2013 for experiments involving humans as well as in accordance with the EU Directive 2010/63/EU for animal experiments.

Informed consent and patient details

The authors declare that this report does not contain any personal information that could lead to the identification of the patient(s).

The authors declare that they obtained a written informed consent from the patients and/or volunteers included in the article. The authors also confirm that the personal details of the patients and/or volunteers have been removed.

Disclosure of interest

The authors declare that they have no competing interest.

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