Neonatology

Original Paper

Neonatology 2020;117:175–181
DOI: 10.1159/000506772

Received: January 21, 2020
Accepted after revision: February 24, 2020
Published online: April 3, 2020

Compliance with Guidelines and Efficacy of Heart Rate Monitoring during Newborn Resuscitation: A Prospective Video Study

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Keywords
Newborn resuscitation · Birth asphyxia · Positive pressure ventilation · Delivery room · Guideline compliance · Heart rate assessment · Pulse oximetry

Abstract
Objective: Newborn resuscitation guidelines recommend initial assessment of heart rate (HR) and initiation of positive pressure ventilation (PPV) within 60 s after birth in non-breathing newborns. Pulse oximeter (PO) and electrocardiogram (ECG) are suggested methods for continuous HR monitoring during resuscitation. Our aim was to evaluate compliance with guidelines and the efficacy of PO versus ECG monitoring in real-life newborn resuscitations. ***Methods:*** In this prospective observational study, we video recorded resuscitations of newborns ≥34 weeks of gestation receiving PPV at birth. ***Results:*** 104 resuscitations were analysed. Median (IQR) time from birth to arrival at the resuscitation bay was 48 (22–68) s ($n = 62$), to initial HR assessment 70 (47–118) s ($n = 61$), and to initiation of PPV 78 (42–118) s ($n = 62$). Initial HR assessment (stethoscope or palpation) and initiation of PPV were achieved within 60 s for 35% of the resuscitated newborns. Time to initial HR assessment and initiating PPV was significantly longer following vaginal deliveries than caesarean sections: 84 (70–139) versus 44 (30–66) s ($p < 0.001$) and 93 (73–139) versus 38 (30–66) s ($p < 0.001$). Time from birth and sensor application to provision of a reliable HR signal from PO versus ECG was 348 (217–524) ($n = 42$) versus 174 (105–277) s ($n = 30$) ($p < 0.001$) and 199 (77–352) ($n = 65$) versus 16 (11–22) s ($n = 52$) ($p < 0.001$). ***Conclusion:*** Initial HR assessment and initiation of PPV were achieved within 60 s after birth in only 1/3 of newborn resuscitations. When applied for continuous HR monitoring, ECG was superior to PO in time to achieve reliable HR signals in real-life resuscitations.

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Introduction

Birth asphyxia remains a leading cause of neonatal mortality [1, 2] and is a major cause of long-term neurologic disability and impairment in children [3, 4]. Newborn resuscitation has the potential to reduce morbidity and mortality caused by birth asphyxia [5]. Newborn resuscitation program (NRP) guidelines state that in non-breathing newborns, the heart rate (HR) should be as-

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sessed and positive pressure ventilation (PPV) initiated within the first 60 s after birth [6, 7]. However, compliance with guidelines is challenging even for trained resuscitation teams [8, 9]. Continuous HR monitoring by pulse oximetry (PO) or electrocardiography (ECG) is essential to guide and evaluate the effect of resuscitative interventions. Studies have demonstrated that ECG is faster in achieving a reliable HR monitoring in healthy newborns under controlled settings [6, 10–12]. However, the efficacy of PO versus ECG for HR monitoring in real-life newborn resuscitation remains unclear.

The objectives of this study were, in apnoeic or inadequately breathing late-preterm and term newborns in a high-resource setting, (i) to describe if time from birth to initial assessment of HR and initiation of PPV comply with current guidelines, and (ii) to compare the efficacy of PO versus ECG in providing a reliable HR signal during real-life newborn resuscitation.

Materials and Methods

Setting

This prospective observational study was conducted from October 1, 2016 until September 30, 2017 at Stavanger University Hospital, Norway, with approximately 4,500 deliveries annually. The department of obstetrics includes a midwifery run low-risk delivery unit, a general labour ward, and two operating rooms for elective and emergency caesarean sections. Each site has a centrally placed resuscitation room with a resuscitation bay, where compromised newborns are brought for stabilization and resuscitation. The resuscitation bays are equipped with a patient monitor (Carescape Monitor B450 or B650, GE Healthcare, Chicago, IL, USA) and basic NRP-recommended resuscitation equipment. The distance from the delivery rooms to the resuscitation room varies between 3 and 20 m (mean 12 m). For caesarean sections, the resuscitation room is adjacent to the operating theatre.

Resuscitation Team and Guideline

A resuscitation team is called upon for high-risk deliveries (i.e., shoulder dystocia, pathologic foetal HRs, and emergency caesarean sections), consisting of a paediatric resident and/or a consulting neonatologist and the midwife or nurse assistant responsible for the delivery. A neonatal nurse, an anaesthesiologist, and/or an anaesthetic nurse can be called upon if needed. All staff involved in newborn resuscitation undergo regular simulation-based training with fortnightly in situ simulation sessions and a yearly whole-day simulation training session. National resuscitation guidelines [13] are based on the International Liaison Committee on Resuscitation (ILCOR) [7] and European Resuscitation Council guidelines on newborn resuscitation [6]. Apnoeic or inadequately breathing newborns not responding to drying and stimulation are immediately brought to the resuscitation bay. Assessing the initial HR (by stethoscope or palpation) and initiating PPV should be accomplished within 60 s after birth. Continuous HR monitoring should be established, either by PO (Masimo LNCS Neo wrap-around sensor, Masimo, Irvine, CA, USA) placed around the newborn's right wrist or hand and/or gel electrode ECG (Neonatal ECG electrodes, CareFusion, San Diego, CA, USA) applied to the newborn's chest. The order of HR sensor application, PO, and/or ECG is left to the discretion of the resuscitation teams.

Data Collection

An "observational incidence report form" was completed for every newborn, documenting if a newborn received PPV after birth. Resuscitations were recorded by video cameras with motion detectors mounted on the resuscitation bays. The patient monitor image displaying PO and ECG data was extracted from the video output of the patient monitor and synchronically stored with the camera recordings. To determine the time from birth, the nurse assistants were instructed to start a stopwatch at the time when the whole body was delivered. When newborns were brought to the resuscitation bay, the stopwatch showing the exact time from birth was presented to the camera. Deferred parental consent was obtained prior to video analysis. For patient and personnel safety, all video recordings were erased after 3 weeks.

Inclusion and Exclusion Criteria

All newborns of gestational age ≥34 weeks who received PPV at birth were eligible for this study. Newborns were excluded when perceived to have adequate respiratory effort upon arrival at the resuscitation bay, if the treatment was not video recorded (i.e., due to technical issues), parents or staff declined participation, or consent could not be obtained within 3 weeks after the incident.

Data Analysis

A single investigator (P.A.B.) reviewed all video recordings using video management software from XProtect Smart Client (Milestone, Copenhagen, Denmark). The respiratory effort of the newborn on arrival at the resuscitation bay was categorized as adequate, inadequate (e.g., grunting or severe retractions), or apnoeic [6, 7]. Drying and stimulation were considered adequate if the newborn received tactile truncal stimulation (drying, chest and back rubs) prior to respiratory support as opposed to excessive stimulation for longer than 15 s or none at all [14]. We registered time and mode of initial HR assessment and time to initiation of and duration of PPV. The time to reliable PO signals was defined as the time from when the sensor was placed around the newborn's hand or wrist until the monitor displayed a continuous pulse wave and HR values for at least 3 s. The time to reliable ECG signals was defined as the time from when all three electrodes were placed until the monitor showed regular QRS complexes. These definitions of reliable PO and ECG signals are in accordance with previously published studies [15–17]. The time to reliable HR monitoring was compared between newborns with 5-min Apgar <7 and ≥7 [18]. Patient and birth characteristics were extracted from medical records.

Statistics

Data were analysed using R-studio version 1.2.1335 (R Core Team 2019, Vienna, Austria), and results presented as number (%) or median (IQR). Groups were compared with Mann-Whitney U test for continuous variables and Fisher's exact test for categorical variables. All reported p values are two sided. $p < 0.05$ was considered statistically significant.

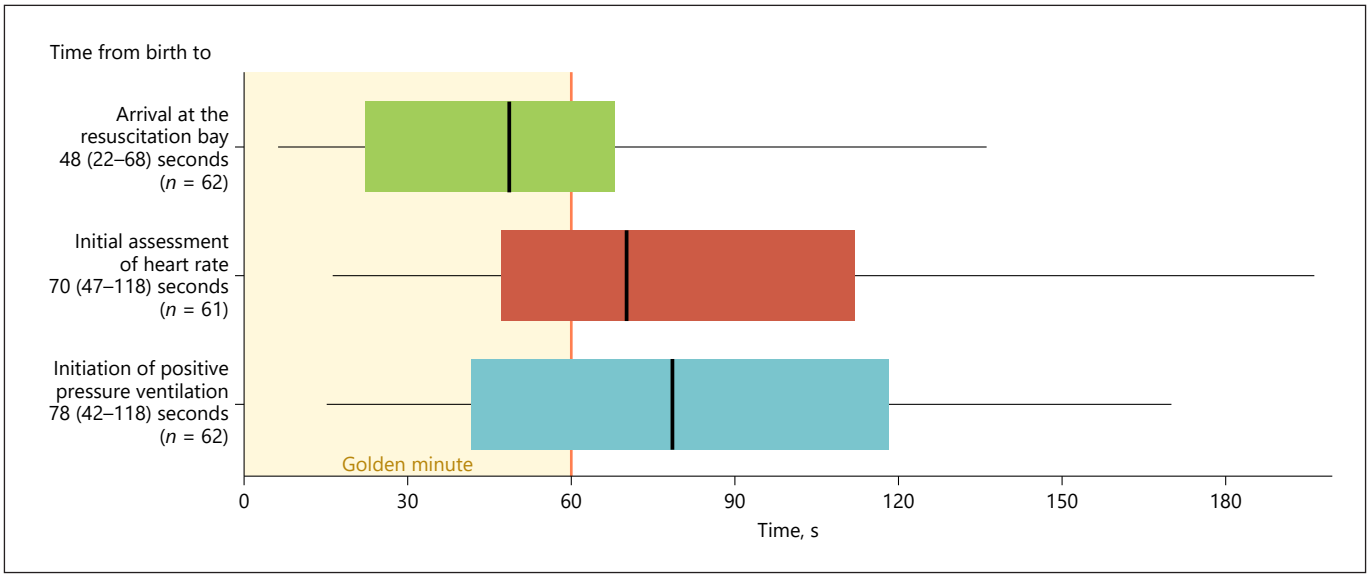

Fig. 1. Timelines from birth to arrival at the resuscitation bay, assessment of initial heart rate, and initiation of positive pressure ventilation for apnoeic or inadequately breathing newborns. The boxes represent the median, first and third quartile and the whiskers represent the range without outliers. Values in headings are shown as median (IQR).

Ethics and Patient Safety

The study was evaluated as non-interventional by the regional ethical committee (2015/1162/REK vest) and approved by the hospital data protection officer. Deferred consent was chosen as only 3% of newborns need PPV at birth in our hospital [19], and obtaining informed consent prior to birth from all parents could evoke unnecessary anxiety. Only the project team members had access to the video recordings. Parents were entitled to view the recording of their newborn, but copies were not provided.

Results

Of 4,619 newborns with gestational age ≥34 weeks born in the study period, 134 (2.9%) were resuscitated with PPV within the first 5 min after birth. Of these, 25 were not included due to missing consent (n = 9) or because the resuscitations were not video recorded (n = 16). During video analysis, five newborns were excluded for having adequate respiratory effort when arriving at the resuscitation bay. The remaining 104 newborns were included in the further analyses; 89 apnoeic and 15 having inadequate respiratory efforts. The characteristics of the included newborns and deliveries are shown in Table 1.

Initial Assessment and Time to Initiate PPV

Upon arrival at the resuscitation bay, 78/104 (75%) of the newborns were adequately dried and stimulated. The

Table 1. Clinical characteristics and modes of deliveries of 104 apnoeic or inadequately breathing newborns receiving positive pressure ventilation

Characteristics of newborns	
Birth weight, g	3,500 (2,984–3,906)
Male gender	67/104 (64%)
Apgar scores	
1-min Apgar	5 (3–6)
5-min Apgar	7 (6–9)
10-min Apgar	9 (8–10)
Umbilical blood values	
Arterial pH	7.17 (0.12)
Arterial base excess	–5.0 (3.5)
Venous pH	7.27 (0.13)
Venous base excess	–5.7 (3.5)
Characteristics of deliveries	
Delivered by vacuum	32/104 (31%)
Delivered by forceps	6/104 (5.8%)
Induced labour	32/104 (31%)
Mode of delivery	
Vaginal cephalic	55/104 (53%)
Vaginal breech	8/104 (7.7%)
Planned caesarean section	2/104 (1.9%)
Emergency caesarean section	39/104 (38%)

Birth weights and Apgar scores are given as median (IQR). Umbilical blood values are given as mean (SD). All other data presented as n (% of included).

Table 2. Time from birth and arrival at the resuscitation bay to initial heart rate assessment and positive pressure ventilation in newborns, either apnoeic or inadequately breathing at birth, by delivery mode

	Total	Vaginal delivery	Caesarean section	*p* value
Time from birth to arrival at the resuscitation bay	48 (22–68) (*n* = 62)	62 (50–116) (*n* = 38)	19 (12–26) (*n* = 24)	<0.001
Time from arrival at the resuscitation bay to				
Initial assessment of heart rate	23 (10–46) (*n* = 99)	32 (12–49) (*n* = 59)	16 (8–40) (*n* = 40)	0.11
Initiation of positive pressure ventilation	22 (12–42) (*n* = 104)	23 (12–40) (*n* = 63)	21 (13–43) (*n* = 41)	0.79
Time from birth to				
Initial assessment of heart rate	70 (47–118) (*n* = 61)	84 (70–139) (*n* = 37)	44 (30–66) (*n* = 24)	<0.001
Initiation of positive pressure ventilation	78 (42–118) (*n* = 62)	93 (73–139) (*n* = 38)	38 (30–66) (*n* = 24)	<0.001

All values are presented as median (IQR) seconds. Groups are compared with Mann-Whitney test (two sided).

initial HR was assessed in 99/104 (95%) newborns, either by stethoscope (*n* = 84) or through palpation (*n* = 15).

The time from birth to arrival at the resuscitation bay was recorded in 62 ventilated newborns. Of these, 22/62 (35%) had the initial HR assessed and 22/62 (35%) PPV initiated within the first 60 s of birth. The timelines from birth to arrival at the resuscitation bay, initial assessment of HR, and initiation of PPV are shown in Figure 1. The time from arrival at the resuscitation bay to the first assessment of HR and initiation of PPV was 23 (10–46) and 22 (12–42) s. PPV was continued for 98 (49–219) s (*n* = 104).

The time from birth and arrival at the resuscitation bay to initial HR assessment and initiation of PPV, by delivery mode, is shown in Table 2. The time to arrival at the resuscitation bay was significantly shorter following caesarean sections than vaginal deliveries, contributing to an earlier initial HR assessment and initiation of PPV.

HR Monitoring

A PO sensor was applied in 98/104 (94%) resuscitations, whereas ECG electrodes were applied in 66/104 (63%). Monitor recordings of PO and ECG were eligible for analysis in 85 and 58 resuscitations. PO failed to provide reliable HR signals in 20/85 (24%) resuscitations whereas ECG failed to provide reliable HR signals in 6/58 (10%) (p = 0.110). There was no difference in time from birth or from arrival at the resuscitation bay to the application of PO and ECG sensors. The time to reliable HR signals was significantly shorter for ECG than for PO (Fig. 2).

The time to PO-based HR signals was 296 (149–393) and 134 (63–291) s in newborns with 5-min Apgar score <7 (*n* = 25) versus ≥7 (*n* = 40) (p = 0.03). There was no significant difference in the time to ECG signals in newborns with 5-min Apgar <7 (*n* = 20) versus ≥7 (*n* = 32); 14 (11–19) and 16 (12–24) s (p = 0.332). The difference between PO and ECG in obtaining reliable HR signals was significant both for newborns with 5-min Apgar score <7 (p < 0.001) and ≥7 (p < 0.001).

Discussion

This prospective study used video recordings to document timelines during 104 real-life resuscitations of apnoeic newborns. We were not able to assess HR or initiate PPV within 60 s after birth in approximately two-thirds of the resuscitations. Similar results were reported by McCarthy et al. [8], having studied high-risk deliveries attended by alerted teams. They did not achieve HR assessment and initiation of PPV within the Golden minute in 2/3 of the resuscitations, despite the newborn arriving at the resuscitation bay at 16 s [8]. The delay in completing tasks in our department was mainly due to a delay from birth to arrival at the centrally placed resuscitation bays following vaginal deliveries. However, Niles et al. [9] reported that only 45% of apnoeic newborns received PPV within 60 s of birth in a setting with resuscitation bays in each delivery room, suggesting that the distance to the resuscitation bay is not decisive. We practise delayed cord clamping, and all vaginally delivered newborns are dried and stimulated on the mother's chest. Birth attendants may hesitate to separate the newborn from the mother, hoping that the newborn will respond to stimulation, thus delaying the transfer of the newborn to the resuscitation bay. Bedside resuscitation units, allowing intact cord resuscitation, could have reduced the time to initiating PPV [20, 21].

Initial HR Assessment and HR Monitoring

Initial HR was mostly assessed by stethoscope, which is the most common method for HR assessment world-

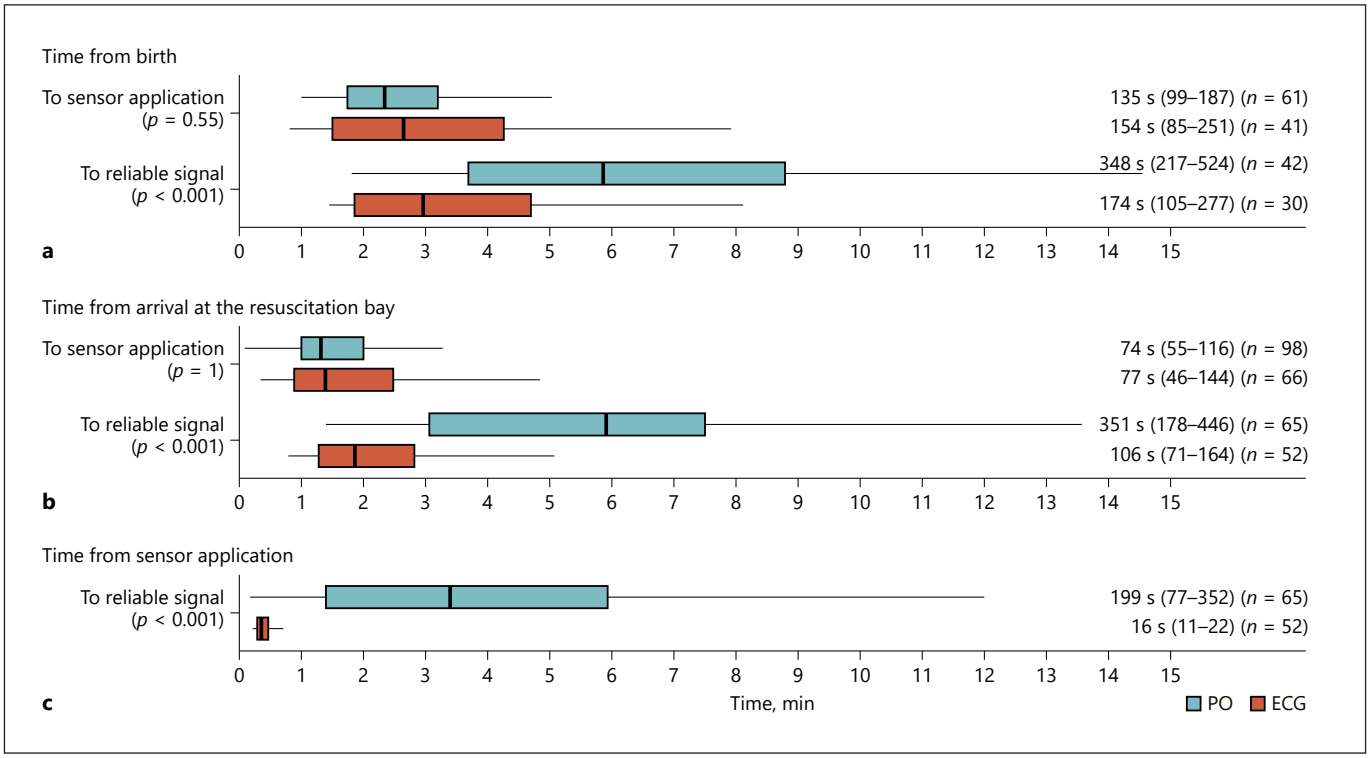

Fig. 2. Efficacy of ECG and PO in achieving a reliable HR monitoring during real-life newborn resuscitation. The boxes represent the median, first and third quartile and the whiskers represent the range without outliers. Values to the right of the boxplots are presented as median seconds (IQR). *p* values are calculated with two-sided Mann-Whitney U test.

wide. However, HR assessment by stethoscope has proven unreliable [22], and more accurate continuous monitoring of HR by PO and ECG during resuscitation is recommended [6, 7].

In our study, reliable HR monitoring through PO was achieved in about 80% of the resuscitations when applied, but only after several minutes' delay. Importantly, the time to reliable HR signals by PO was significantly longer in newborns with 5-min Apgar score <7, possibly due to poor circulation of the extremities in more severely compromised newborns. Consequently, the team must rely on repeated manual HR assessments to guide the resuscitation during the first critical minutes, at the expense of personnel resources and reliable HR feedback [23, 24]. Our findings are not in accordance with earlier studies, which have demonstrated that reliable HR monitoring by PO can be achieved within 12–32 s from sensor application and 68–122 s after birth [16, 17, 25–28]. However, these studies were mainly conducted on healthy newborns or during high-risk deliveries with personnel dedicated to apply PO sensors immediately after birth.

Several studies suggest that ECG is a more effective method for determining HR during the first minutes after birth [17, 25, 26, 29], in agreement with our study. Moreover, ECG was equally effective in newborns with 5-min Apgar scores <7. Our findings support the recommendation of ECG as an alternative to PO for HR monitoring during newborn resuscitation. However, the use of ECG does not replace the need for PO to assess the oxygenation.

Troublesome fixation of ECG leads on wet skin is an issue during newborn resuscitation [10]. We found that this challenge applied to PO sensors as well. The occasional vigorous handling of the newborn during resuscitation, combined with the newborn's wet skin, disrupted or delayed the fixation of both the PO wrap-around sensor and the ECG gel electrodes. Consequently, the sensors had to be reapplied or replaced, further delaying the time to obtain reliable HR. This was not a frequent concern, but has likely contributed to the delay in achieving continuous HR monitoring in our real-life study compared to studies with more con-

trolled settings. Nevertheless, these aspects of real-life resuscitations should be taken into account when comparing the reliability of different methods of continuous HR monitoring in newborns.

Limitations

Our study has limitations. We do not have information about the management of the newborns prior to arrival at the resuscitation bay. Stimulation attempts in the delivery room or events where the newborn collapsed after initial crying are both plausible reasons for a delayed transfer for resuscitation. Due to technical issues, 16 resuscitations were not video recorded, and another 13 newborns did not have HR monitor recordings. However, these incidents occurred randomly and should not bias the results.

Conclusion

In this study with video recordings of newborn resuscitations, initial HR assessment and initiation of PPV were not achieved within the recommended 60 s after birth in the majority of resuscitations, largely due to a delay in transfer to centrally placed resuscitation bays. When PO or ECG was applied for continuous HR monitoring during real-life resuscitations, reliable HR signals were achieved substantially faster by ECG than by PO. The time to reliable HR signals by PO was significantly longer in newborns with 5-min Apgar score <7 versus ≥7, whereas ECG was equally effective in both groups.

Acknowledgement

We thank all the midwives, nurse assistants, and physicians working in the labour units at Stavanger University Hospital, and parents with their newborns participating in this study.

Statement of Ethics

The study was evaluated as non-interventional by the regional ethical committee (2015/1162/REK vest) and approved by the hospital data protection officer. Deferred consent was chosen as only 3% of newborns need PPV at birth in our hospital [19], and obtaining informed consent prior to birth from all parents could evoke unnecessary anxiety.

Disclosure Statement

The authors have no conflicts of interest to declare.

Funding Sources

P.A.B. and S.I.R. have received unconditional grants from Laerdal Foundations.

Author Contributions

All authors designed the study protocol. P.A.B. and S.I.R. practically implemented, supervised, and carried out the study and the data collection on site. P.A.B. analysed all video material. All authors participated in the interpretation of the results. P.A.B. drafted the initial manuscript. All authors read and improved the final manuscript.

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