Figure 1. The PreSSUB 3.0 system. The telemedicine device is securely mounted to the ceiling of the ambulance (A) and allows bidirectional audiovisual communication between the patient and the teleconsultant via integration of a microphone, speakers, a screen and a 360° view camera (B). The teleconsultant has mobile access to the telemedicine platform using a lightweight laptop computer with touch screen, integrated microphone, speakers and a webcam (C).
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The first generation telemedicine systems were 'point-to-point' models over landlines, confining health care providers to fixed workstations within hospitals [9]. The involvement of the World Wide Web (WWW) heralded the second generation of telemedicine, allowing teleconsultations to be conducted from anywhere at any time [9]. Third generation telemedicine (telemedicine 3.0) leverages mobile broadband connectivity to expedite prehospital teleconsultations between patients in moving ambulances and remote healthcare providers. Prehospital transmission of ECG is widely used to reduce the time-to-treatment and to improve outcomes in patients with acute myocardial infarction [10–12]. Remote assisted abdominal ultrasound [13] and virtual presence of emergency physicians have been investigated to support paramedics in the field [14,15]. Prehospital telemedicine for stroke promises to be a feasible [16] and reliable [17] solution to reduce door-to-needle times [18].

Methods

We report on the Feasibility of AmbulanCe-based Telemedicine (FACT) study, which is part of the Prehospital Stroke Study at the Universitair Ziekenhuis Brussel (PreSSUB) [17,19]. The aim of this prospective study is to investigate the safety, the technical feasibility and the reliability of in-ambulance telemedicine using a prototype third generation telemedicine system (PreSSUB 3.0). To avoid treatment delay in emergency settings, informed consent was obtained on opt-out basis, followed by written informed consent from patients or legal representatives after the acute phase. All patients gave written informed consent for participation in the study. The individual in this manuscript has given written informed consent (as outlined in PLOS consent form) to publish these case details. The study protocol and the consent process were approved by the ethics committee of the Universitair Ziekenhuis Brussel (B.U.N. 143201317990) on January 8th 2014. The FACT study was registered at clinicaltrials.gov (NCT02119598). As the study duration was shorter than expected due to high enrolment rates, registration of the study was completed only after patient enrolment was terminated. The authors confirm that all ongoing and related trials for this intervention are registered.

PreSSUB 3.0 system

Building on our experience involving in-ambulance telemedicine in healthy volunteers [17], we equipped a routine ambulance used in emergency interventions with a system for real-time bidirectional audio-video communication, allowing virtual face-to-face interaction between patients and teleconsultants (Figure 1). Other functionalities include the automated transmission of vital parameters (heart rate, blood oxygen saturation, systolic and diastolic blood pressure), glycemia, electronic patient identification (eID), electronic reporting and prehospital notification of the in-hospital team by short message service (SMS).

The architecture of the PreSSUB 3.0 device in the ambulance consists of a laptop computer (Dell Latitude XT3, Dell, Round Rock, Texas, USA) operating on 64-bit Windows 7 (Microsoft Corp., Redmond, USA) with touch screen and integrated microphone and loudspeaker, connected to a 360° view Internet protocol camera (Mobotix Q24, Mobotix AG, Winnweiler, Germany) and a 4G router (RUT550 LTE, Teltonika, Vilnius, Lithuania). The camera offers remote digital pan, tilt and zoom (8X) functionalities, as well as user-defined preset commands. Real-time audiovisual and vital data are transmitted over a mobile broadband connection (3G/4G, Belgacom) through a transmission unit in the ambulance and a roof antenna. The video stream is integrated into a telemedicine platform (WiPaM, IXSyS, Hasselt, Belgium) that also hosts the proprietary software for Unassisted TeleStroke Scale (UTSS) assessment. This scale was developed in Dutch, French and English and validated as a rapid tool for assessment of stroke severity through telemedicine, without the assistance of a third party at the patients' bedside [17,19].

Image size and compression quality of the video image were kept constant during the study at 16 images per second in a standard VGA format of 640×480 pixels. Data privacy was secured by password-protected login, role-based access control, hypertext transfer protocol secure encryption, and transfer through a virtual private network. Wireless point-of-care devices for measurement of blood pressure and glycemia (Clever Chek TD3250-C, RDSM, Hasselt, Belgium), blood oxygen saturation (CMS 60 Pulse Oximeter, Contec TM, Qinhuangdao, China) and an eID card reader, were incorporated in the system. Prehospital notification was initiated by the teleconsultant by sending an

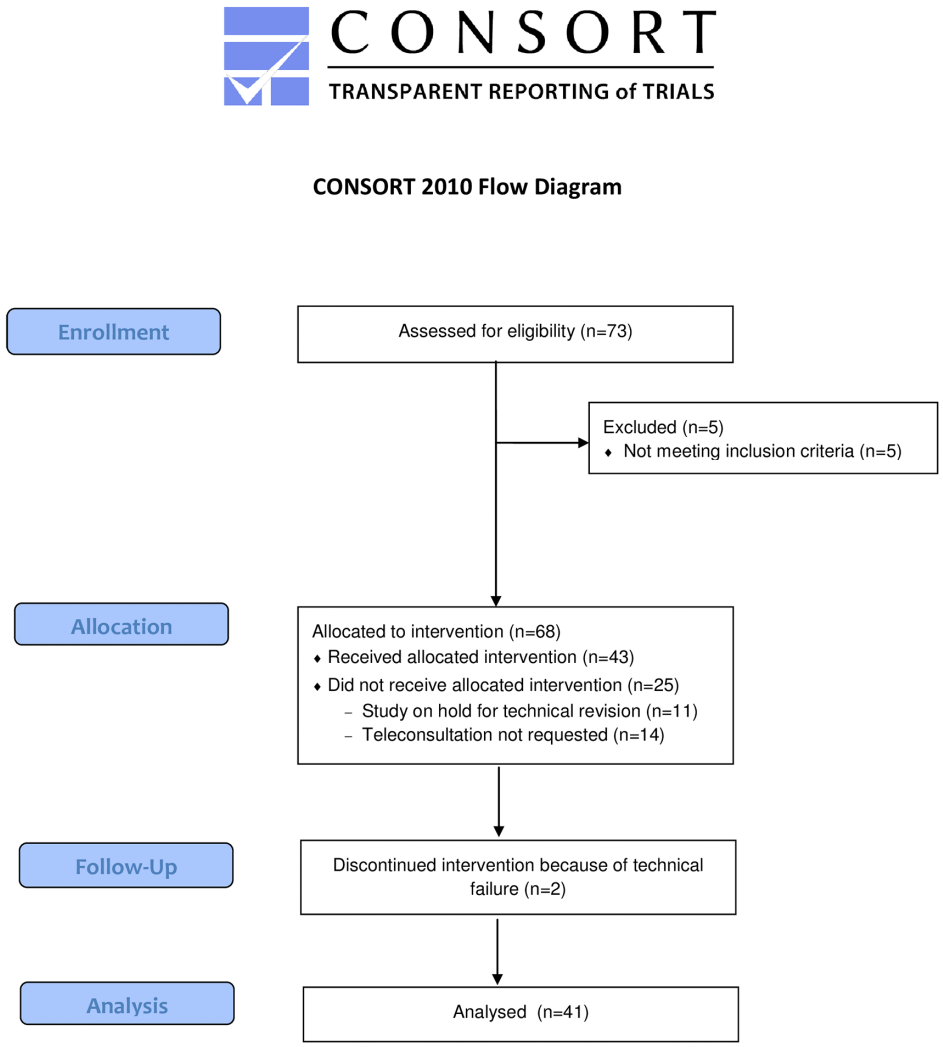

Figure 2. Flow diagram of the FACT study.
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automated SMS message from the telemedicine platform to the cell phones of in-hospital caregivers, informing them that an electronic report of the prehospital consultation was available on a designated, password protected website.

To guarantee mobility and to facilitate 24/7 availability, the teleconsultants used lightweight laptop computers (Dell XPS, Dell, Round Rock, Texas, USA) with touch screen, integrated microphones, loudspeakers and webcams and a 64-bit Windows 8 or Windows 8.1 operating system (Microsoft Corp., Redmond, USA). To access ambulance data and to control the camera in real-time they used secured WiFi networks or a 4G modem (Huawei E398, Huawei Technologies Co, Shenzhen, China) and a standard WWW browser (Opera 19.0, Opera Software ASA, Oslo, Norway). To obtain bi-directional audiocommunication, an Internet phone service was used (Skype TM, version 6/14/59.104, Skype/Microsoft Corp. Redmond, USA).

Study participants

All patients ($\geq$18 years) transported during emergency missions by a Prehospital Intervention Team (PIT) of the Universitair Ziekenhuis Brussel from February 13th to February 28th 2014 were eligible for inclusion in the study. The PIT consists of two Emergency Medical Technicians (EMT) and one Certified Emergency Nurse (CEN) or Critical Care Registered Nurse (CCRN). Secondary patient transports or inter-hospital transfers were not included. Patients were investigated by one of three teleconsultants (LY, RJVH and RB) who had at least five years of clinical experience in neurological emergencies. The study did not interfere with PIT dispatches, which occurred according to local guidelines, nor with the standing orders. Activation of the device was easily done by the nurse in the ambulance via one-button activation. All CEN and CCRN nurses (n = 16) followed a three-year general training program, a one-year training program in emergency care and additional field experience training. Prior to the start of the FACT study, they received training on the use of the PreSSUB 3.0 system.

A control population was included, consisting of all patients transported by the PIT of the UZ Brussel during emergency missions between January 1st and January 31th 2014.

Data collection and analysis

The bandwidth of the mobile connection and the total amount of data transfer were measured during the teleconsultations using an open-source bandwidth monitor (BitMeter OS v0.7.5, Copy-

Table 1. Patient and intervention characteristics.*

	FACT	Control group	*P* value
	(n = 41)	*(n = 134)*	
Patient characteristics			
Male gender[§]	20 (48.8%)	57 (42.5%)	*0.299*
Age (years) [#]	57.0 (38.5–80.5)	65.0 (37.8–78.0)	*0.905*
Prehospital Glasgow Coma Scale score[#]	15 (15–15)	15 (14–15)	*0.514*
Prehospital diagnosis PIT[§]			
Cardiac arrest	0 (0.0%)	1 (0.7%)	*1.000*
Serious trauma	4 (9.8%)	6 (4.5%)	*0.247*
Respiratory distress	5 (12.2%)	11 (8.2%)	*0.535*
Acute coronary syndrome	0 (0.0%)	4 (3.0%)	*0.574*
Stroke	3 (7.3%)	9 (6.7%)	*1.000*
Intoxication	3 (7.3%)	10 (7.5%)	*1.000*
Other	26 (63.4%)	93 (69.4%)	*0.566*
Intervention characteristics			
Outside office hours[§]	28 (68.3%)	71 (53.0%)	*0.059*
PIT intervention time (minutes) [#]	36 (29–51)	36 (28–47)	*0.625*

* Data given as number (percentage) or as median (interquartile range). [§]Fisher's exact test. [#]Mann-Whitney U test.
Abbreviations: FACT, Feasibility of AmbulanCe-based Telemedicine; PIT, Prehospital Intervention Team.
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right 2011 Rob Dawson) and screen recordings of all teleconsultations were obtained (BB Flashback 4.1, Blueberry software Ltd., Birmingham, United Kingdom). Any issue with hardware, software, connectivity or safety was recorded.

Data on patient characteristics (demographics, prehospital and in-hospital diagnosis) and prehospital time intervals were retrieved from the reports of the teleconsultants, PIT reports and the medical hospital records. For the control populations, data on patient characteristics (demographics, prehospital Glasgow Coma Scale and prehospital diagnosis) and intervention characteristics (interventions outside office hours, PIT intervention time) were retrieved from the PIT reports and the medical hospital records.

The quality of the audio-video connection and the user-friendliness of the system was rated by the teleconsultants and the nurses using Likert-scales [20]. Telephone-based or real-life debriefings were conducted immediately after the teleconsultation when necessary and all nurses were interviewed in person after the study to obtain detailed feedback.

Statistical analysis was performed using SPSS statistics version 22.0 (SPSS, Chicago, IL, USA). Technical data (bandwidth and data transfer) and patient demographics (age) were not normally

Table 2. Detailed overview of the prehospital telemedicine diagnoses and the final in-hospital diagnose.

	Prehospital telemedicine diagnosis	Final in-hospital diagnosis
Neurological disease	8 (19.5%)	8 (19.5%)
Stroke	5 (12.2%)	3 (7.3%)
Other	3 (7.3%)	5 (12.2%)
Non-neurological disease	29	33 (80.5%)
Trauma	10 (24.4%)	10 (24.4%)
Respiratory disease	8 (19.5%)	9 (22.0%)
Gastro-intestinal disease	3 (7.3%)	4 (9.8%)
Intoxication	3 (7.3%)	3 (7.3%)
Acute pain	2 (4.9%)	3 (7.3%)
Labor	2 (4.9%)	1 (2.4%)
Dysglycemia	1 (2.4%)	1 (2.4%)
Vascular disease	0 (0.0%)	1 (2.4%)
Other	0 (0.0%)	1 (2.4%)
Unknown	4 (9.8%)	0 (0.0%)

doi:10.1371/journal.pone.0110043.t002

Table 3. Bandwidth and data transfer during prehospital teleconsultation*.

	Upload	Download
	(from the teleconsultant to the ambulance)	(from the ambulance to the teleconsultant)
Mean speed (kB/s)	163 (139–221)	54 (19–113)
Maximal speed (kB/s)	812 (641–1060)	167 (84–377)
Total data transfer (MB)	102 (74–180)	35 (13–57)

* Data given as median (interquartile range).
Abbreviations: kB/s: kilobytes per second; MB: megabyte.
doi:10.1371/journal.pone.0110043.t003

distributed and are therefore presented as medians (interquartile ranges, IQR). Other data are presented as success rates (number of successful registrations divided by the number of attempts ×100). The agreement between the prehospital telediagnosis and the final in-hospital diagnosis was evaluated using the proportion of overall agreement and κ statistics.

Results

Patient population

During the study, the PIT of the Universitair Ziekenhuis Brussel transported 73 patients of which 68 patients met the inclusion criteria. Forty-three attempts were made to perform a prehospital teleconsultation. In 11 cases no attempt was made, as the telemedicine system was being revised for technical reasons and in 14 cases, teleconsultation was not requested by the PIT. This occurred mainly because of patient characteristics (aggression, psychiatric disease, labor) (Figure 2).

Prehospital teleconsultation was obtained in 41 out of 43 cases (success rate, 95.3%). Failures resulted from technical problems; in one case the device was not fully functional because it initiated in safe mode after forced shut down during the previous session. In another case, the failure resulted from a power issue as the battery of the system had not been recharged. Bidirectional audio-video communication was established in 39 cases. In 2 cases, only unidirectional video communication from the ambulance to the teleconsultant was obtained because of low bandwidth. A video fragment of a prehospital teleconsultation is available as supplemental material (Video S1).

Patient data and medical data

The patients' median age was 57.0 years (IQR, 38.5–80.5). Twenty males (48.8%) and 21 females (51.2%) participated. Teleconsultation was performed in the language preferred by the patient, which was French in 33 cases (80.5%) and Dutch in 8 cases (19.5%). No significant differences in patient demographics were found between the study group and the control group (Table 1). None of the eligible patients refused participation.

Patient identification was attempted if the patient's eID card was available (n = 19). In 3 cases, the eID data was not transmitted by the system (success rate, 84.2%). Registration of the blood pressure and the heart rate via the PreSSUB system was performed during 33 sessions. Successful registration of the systolic and diastolic blood pressure was obtained in 78.7%. Registration of the heart rate was successful in 84.8%. All failures resulted from data transmission issues between the device and the telemedicine platform. Measurement of blood oxygen saturation was attempted in 31 cases, with successful registration in 80.6%. One failure resulted from battery failure of the device, all other failures resulted from data transmission issues. In 8 cases, a non-PreSSUB device (Lifepak 15, Physio-control, Redmond, USA) was used for registration of blood pressure, heart rate and blood oxygen saturation. In 2 patients, blood oxygen saturation could not be measured due to agitation. Glycemia was successfully registered in 64.0% (n = 25). One device error occurred, other failures resulted from data transmission issues. In 6 cases a non-PreSSUB device (Accu-Chek Performa, Roche, Basel, Switzerland) was used for registration of glycemia. Data obtained with non-PreSSUB devices were transmitted verbally to the teleconsultant when possible.

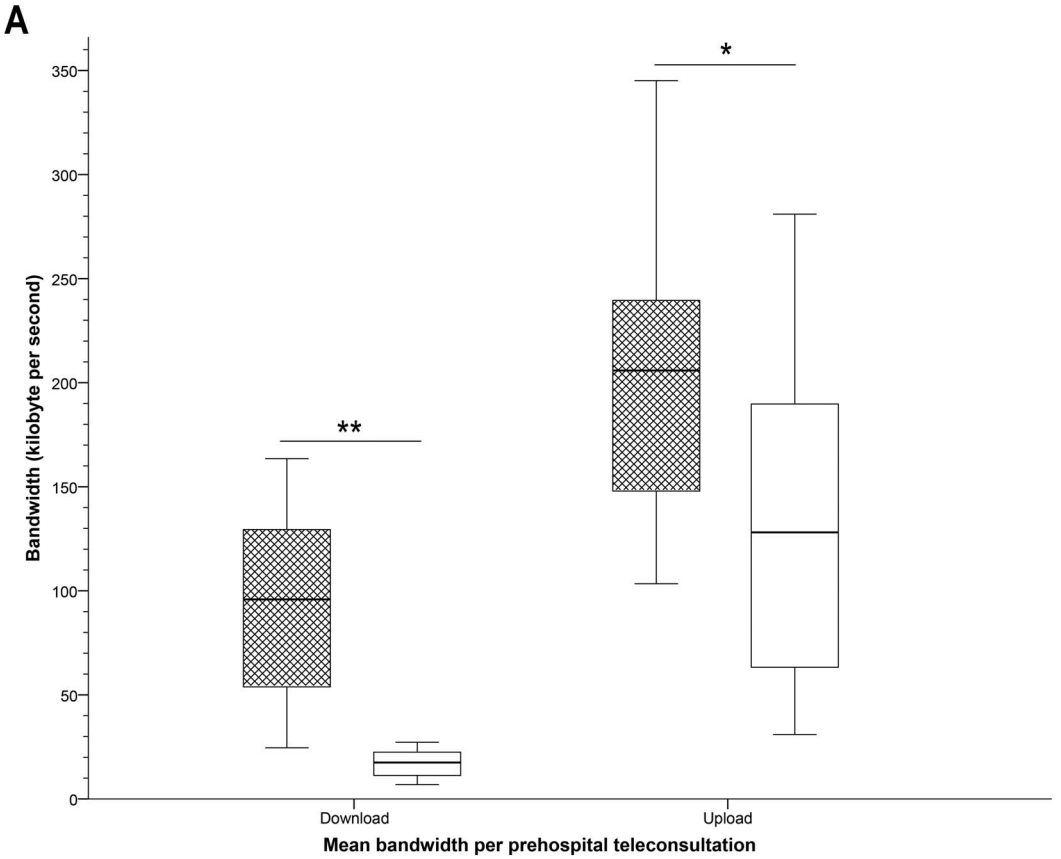
Blood pressure abnormalities were noted in 77.5% of available registrations and included systolic hypertension (SBP ≥ 140 mmHg) in 58.8%, diastolic hypertension (DBP ≥90 mmHg) in 45.4% and diastolic hypotension (DBP ≤60 mmHg) in 12.1% [21,22]. Six patients presented with a hypertensive urgency (SBP >180 or DBP >120) [22]. Abnormalities in heart rate occurred in 37.1%, with tachycardia (HR >100 bpm) in 25.7% and bradycardia (HR <60 bpm) in 11.4% [23]. Three patients presented with a relevant cardiac arrhythmia (7.3%), involving atrial fibrillation with ventricular response >150 bpm in 2 patients and a cardiac arrest requiring cardiopulmonary resuscitation in one patient. Only in the latter case assistance of an emergency physician was called on-site. Hypoxemia (spO2 <95%) was present in 20.7% and 3 patients presented with severe hypoxemia (spO2 <90%). Dysglycemia was present in 16.7%, all involving hyperglycemia (glycemia >200 mg/dl).

In patients with an emergency call for suspicion of an acute neurological disease, the UTSS [17,19] was used to identify stroke and to evaluate the stroke severity.

In 7 patients (17.1%), a neurological condition was suspected based on information from the emergency medical services (EMS) dispatch, with suspicion of epileptic seizure, acute stroke and coma in respectively 3, 2 and 2 patients. In 6 out of the 7 cases, an attempt was made to perform an UTSS assessment. In 2 patients (33.3%), the assessment was completed before arrival at the hospital. Only partial evaluation was possible in 4 cases (66.6%), due to technical issues related to connectivity in one case and due to patient characteristics related to the disease (vomiting, coma, aphasia) in 3 cases.

A preliminary prehospital diagnosis, based on the results of the clinical examination and the vital parameters, was formulated by the teleconsultants in 37 cases (90.2%) (Table 2). Failure to obtain a prehospital diagnosis was the result of connectivity issues with permanent or temporary disconnection during the teleconsultation in 4 cases.

There was a high degree of agreement between the prehospital telediagnosis and the final inhospital diagnosis. The proportion of overall agreement and the κ statistic for distinguishing neurological disease from non-neurological disease were 0.98 and 0.92, respectively ($P<0.001$). All patients with in-hospital diagnosis of stroke were correctly identified prehospitally (proportion of overall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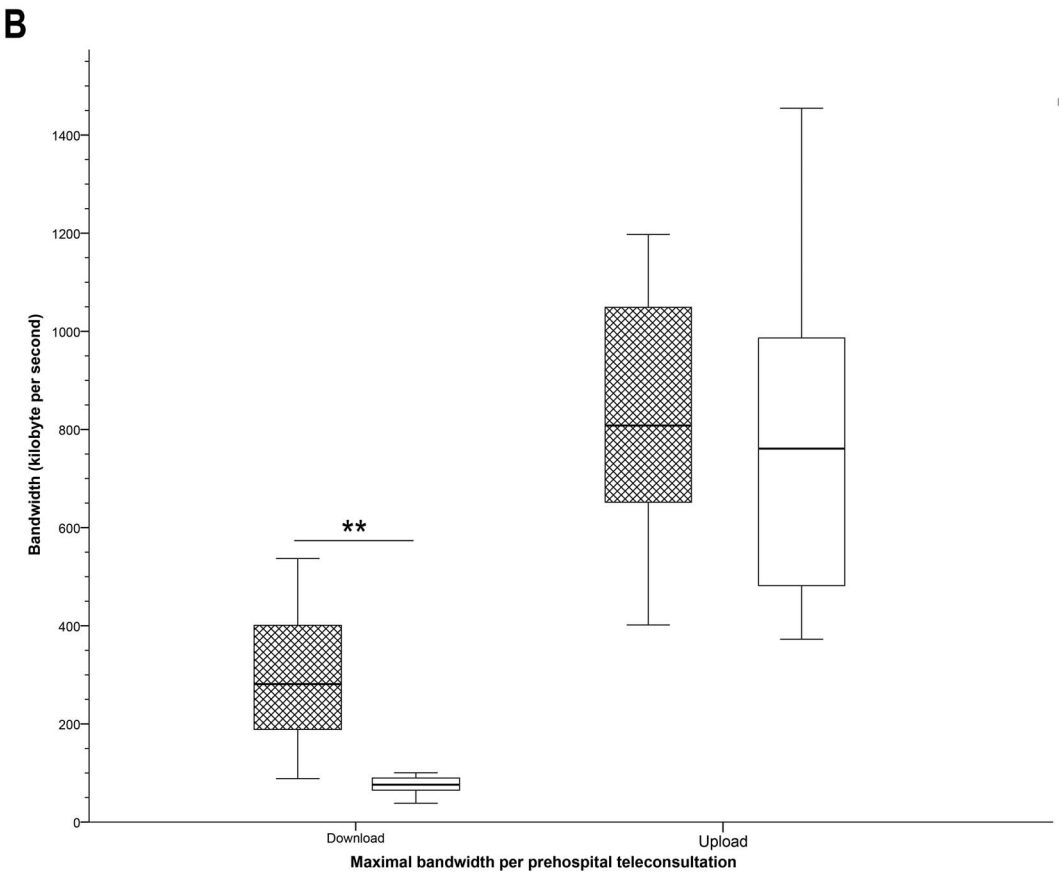
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