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ORIGINAL RESEARCH

Increase in regional cerebral saturation after elective electrical cardioversion of atrial fibrillation is only transient and without beneficial effects on neuropsychological functioning: cerebral saturation during electrical cardioversion

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Abstract
We aimed to confirm the positive association between a successful electrical cardioversion (ECV) and increase in $SctO_2$ and investigated whether this increase is persisting or not. Secondary, the influence of a successful ECV on the neuropsychological function and the association with $SctO_2$ was assessed as well. $SctO_2$ was measured continuously during elective ECV using near-infrared spectroscopy. Measurements started before induction of sedation and ended 15 min after awakening. A second measurement took place 4 to 6 weeks after ECV. To assess neuropsychological functioning, patients performed standardized neuropsychological tests before ECV and at follow-up and were compared to healthy volunteers as control group. $SctO_2$ was measured in 60 patients during elective ECV. ECV was successful in 50 AF patients, while in ten patients sinus rhythm was not obtained. $SctO_2$ increased immediately after successful ECV in 50 patients (1% (− 5 to 4); p = 0.031), but not after unsuccessful ECV in 10 patients (− 1% (− 5;3); p = 0.481). This $SctO_2$ change was positively correlated with the instant change in blood pressure ($R^2 = 0.391$; p = 0.004). At follow-up, $SctO_2$ values were no longer increased. Nevertheless, successful ECV improved the patient's quality of life but did not influence neuropsychological functioning at follow-up. A transient, instant $SctO_2$ increase was observed after successful ECV. This temporary increase in $SctO_2$ did not influence the neuropsychological functioning of the patients. Though, the quality of life of patients with a successful ECV improved.

Keywords Electrical cardioversion · Atrial fibrillation · Near-infrared spectroscopy · Cerebral saturation · Neuropsychological functioning · Cerebral oxygenation

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1 Introduction

With an estimated prevalence of 4–17% in patients over 60 years, atrial fibrillation (AF) is the most common cardiac arrhythmia in Europe [1]. As cardiac arrhythmias such as AF might induce cerebral microemboli and are known to be associated with a reduced cerebral perfusion pressure, stroke and cognitive disorders are commonly observed adverse cerebral phenomena [2, 3]. Nevertheless, several studies showed that the cognitive decline after AF is independent of cerebral infarction and general brain hypoperfusion might play an important role in the development of cognitive decline [2, 4–6]. Therefore, advanced neuromonitoring tools could provide more insight into the cerebral pathophysiology during AF which might affect the future treatment of AF.

Currently, regional cerebral saturation ($SctO_2$) can be measured continuously and non-invasively at the microvascular level using near-infrared spectroscopy (NIRS) technology. Incorporated into a sensor applied to the forehead of the patient, the emitted near-infrared light travels in a banana shape trail through skin, skull and underlying tissues, where it is scattered, reflected and absorbed by chromophores such as oxygenated and deoxygenated haemoglobin. The remaining reflected light is collected by the detectors. Since each chromophore has an unique absorption spectrum, differentiation based on the absorption characteristics is possible [7]. In contrast to pulse oximetry, this technique is independent of a pulsatile signal. As a final result, NIRS technology monitors the local $SctO_2$ in the frontal lobe ta a depth of 1.5 cm. As a final result, NIRS technology monitors the local $SctO_2$ in the frontal lobe ta a depth of 1.5 cm.

Previously, Wutzler et al. demonstrated in a small cohort of AF patients an increase in $SctO_2$ after successful electrical cardioversion (ECV) independent of arterial blood pressure, heart rate and arterial oxygen saturation [8]. Referring to these results, a rapid restoration of the sinus rhythm is of paramount importance to ensure adequate cerebral perfusion and could therefore limit the cognitive decline after AF. Unfortunately, it is currently unknown whether this improvement in $SctO_2$ after successful ECV is long-lasting or only a temporary post-procedural phenomenon.

Hence, this current prospective study aimed to confirm the positive association between a successful ECV and increase in $SctO_2$ and investigated whether this increase is persisting or not. Secondary, the influence of a successful ECV on the neuropsychological functioning and the association with $SctO_2$ was assessed by extensive neuropsychological testing, with the inclusion of a group of matched healthy volunteers as control group (NCT02378155).

2 Methods

This study was a prospective, monocenter trial at Ziekenhuis Oost-Limburg in Genk, Belgium. The study complied with the declaration of Helsinki and the protocol was approved by the local ethics committee (14/091U). Written informed consent was obtained from all participants. Two well defined study populations were included namely adult patients with paroxysmal or persistent AF who were treated with ECV as well as gender- and aged-matched healthy volunteers who were used as control group for neuropsychological testing. Patient's medical history was assessed by means of a standardized questionnaire and the patient's medical record. Patients with chronic obstructive pulmonary disease GOLD class III–IV, carotid artery disease or previous cardiopulmonary resuscitation were excluded.

2.1 Electrical direct current cardioversion procedure

ECV was carried out in a fasting state. Patients received 4L oxygen per minute via a facial mask or nasal cannula. In case of arterial desaturation, measured via pulse oximetry ($SpO_2 < 90\%$), the administered oxygen was increased to 10L per minute until desaturation was reversed ($SpO_2 > 95\%$). At the start of the procedure, patients were sedated using propofol (Diprivan 1%; AstraZeneca Canada Inc., Mississauga, Canada) based on the patient's body weight (0.075–0.1 mg/kg). The paddles of the HeartStart MRx defibrillator (Philips Healthcare, Best, The Netherlands) were placed in an anterior-lateral position. Only when the patient had a pacemaker or cardiac resynchronization therapy device, the paddles were placed in an anterior–posterior position. Synchronized, biphasic electrical shocks were administered with an increasing energy level (150 Joule–170 or 200–200 Joule) until the heart rhythm was converted towards a sinus rhythm. A maximum of three shocks was applied.

2.2 $SctO_2$ monitoring

Immediately after the patient's medical history questionnaire was completed, one sensor of the SenSmart™ (Nonin Medical Inc., Plymouth, MN, USA) was positioned at the right side of the forehead to measure $SctO_2$ continuously during ECV until 15 min after the patient regained consciousness. Based on available literature, left and right $SctO_2$ have been shown to be rather similar through which, in this research context, bilateral $SctO_2$ monitoring would not have had an added value on top of unilateral $SctO_2$ measurements [9, 10]. The calculated rSO2 values, also the one measured at follow-up, are derived from measurements of at least five

min. Additionally, heart rhythm and rate, respiration rate and pulse oximetry (Philips Healthcare, Best, The Netherlands) were monitored continuously as well. Furthermore, non-invasive arterial blood pressure (Comfort Care Adult; Philips Healthcare, Best, The Netherlands) was measured at four well-defined time points, i.e. before sedation induction, when the patient was optimally sedated, immediately after the administration of the electrical shock and 15 min after regaining consciousness. At follow-up—4 to 6 weeks after ECV—a second 5 min measurement of the $SctO_2$ was performed. All measurements were carried out in supine position.

2.3 Neuropsychological test battery

The neuropsychological test battery was constructed based on validated, standardized tests which are known for their high reliability. Both the healthy volunteers and the AF patients completed a standardized neuropsychological test battery including auditory verbal learning test (AVLT), the mini-mental state examination (MMSE), the trail making test and the digit-symbol coding examination. In this way the short term memory, working memory, attention, reaction rate and hand–eye coordination of the patient were assessed [11]. Both the AVLT and trail making test were previously used in AF research [12]. The RAND 36 Health Survey (SF-36) was added to evaluate the quality of life, which has been frequently used and validated in arrhythmia studies [13, 14]. All neuropsychological tests were performed twice per subject namely an hour before ECV and 4 to 6 weeks after ECV.

2.4 Statistics

Equal distribution was tested using a Shapiro–Wilk test. Continuous data which follow a normal distribution are presented as mean ± standard deviation, while non-normal distributed data are represented as median and interquartile range [Q1; Q3]. Categorical data are presented as n (%). A student-test and Mann–Whitney U test was used to compare normally and not normally distributed continuous data between two groups, respectively. A Chi-Square test was performed for categorical data. Consequently, a one-way ANOVA or nonparametric Kruskal–Wallis test was used to compare demographic data and the neurophysiological results between multiple groups, i.e. patients with an unsuccessful ECV, patients with a successful ECV and healthy volunteers. The total amount of patients needed was 46 to achieve a power (1−β) of 80% with a significance level (α) of 0.05 according to a power calculation for the primary outcome. Also a power calculation for the neuropsychological testing was performed. To reach a significance level (α) of 0.05 and a power (1−β) of 80% a minimum of 12 patients were needed for the first test and 8 patients for the second test. To have a certain available reserve we opt to include 20 healthy volunteers. Post hoc analyses were performed using the Fisher's Least Square Difference (normally distributed data) or a Mann–Whitney U test (after Kruskal–Wallis H analysis). Correlation analyses were performed using a Pearson or nonparametric Spearman correlation. Differences are considered significant when p value < 0.05. Statistical analysis was performed using the Statistical Package for Social Sciences release 22.0 (IBM® SPSS® Inc.; Chicago, Illinois, USA).

3 Results

In total, 89 subjects were screened for inclusion, 20 healthy volunteers and 69 patients who received ECV. Out of the sixty-nine patients who received ECV, data from 60 patients could be analysed. While 50 patients experienced successful ECV, sinus rhythm was not restored in 10 patients (unsuccessful ECV) (Fig. 1). Baseline characteristics were similar between these three study groups (Table 1). Furthermore, baseline $SctO_2$ values were similar in both the AF patients with a successful and unsuccessful ECV.

3.1 Influences of successful electrical cardioversion on $SctO_2$

Immediately after induction of sedation, $SctO_2$ decreased in patients with a successful ECV (− 1% [− 5; 4]; $p = 0.013$) compared to baseline $SctO_2$ values. Subsequently, the $SctO_2$ reduced with an additional 2% ([− 4; 0]; $p < 0.001$) during ECV. Once sinus rhythm was restored, $SctO_2$ values increased with a maximum of 6% [3; 9] above baseline $SctO_2$ values ($p < 0.001$). When consciousness was regained an average increase of 1% [5; 4] was observed compared to baseline $SctO_2$ values ($p = 0.031$; Fig. 2 and Table 2). Four to six weeks after successful ECV (35 days [29; 42]), the observed increase in $SctO_2$ values was not sustained as there was no difference between baseline $SctO_2$ and $SctO_2$ values measured at follow-up ($p = 0.077$). After adjustment for duration of atrial fibrillation (in days), change in heart rate and mean arterial pressure, the change in $SctO_2$ during ECV sustained with an adjusted odds ratio of 1.371 (95% CI 1.082–1.739; p = 0.009).

Out of the 50 patients with a successful ECV, 38 patients remained in sinus rhythm at follow-up. These patients had higher $SctO_2$ values after ECV (71.91% ± 6.04) as compared to baseline $SctO_2$ values (70.16% ± 6; p = 0.007). At follow-up, the measured SctO2 values did no longer differ from baseline SctO2 values in both patients who remained in sinus rhythm (67.88% ± 4.71; p = 0.278) and in patients who did not. In the other 12 patients who had successful

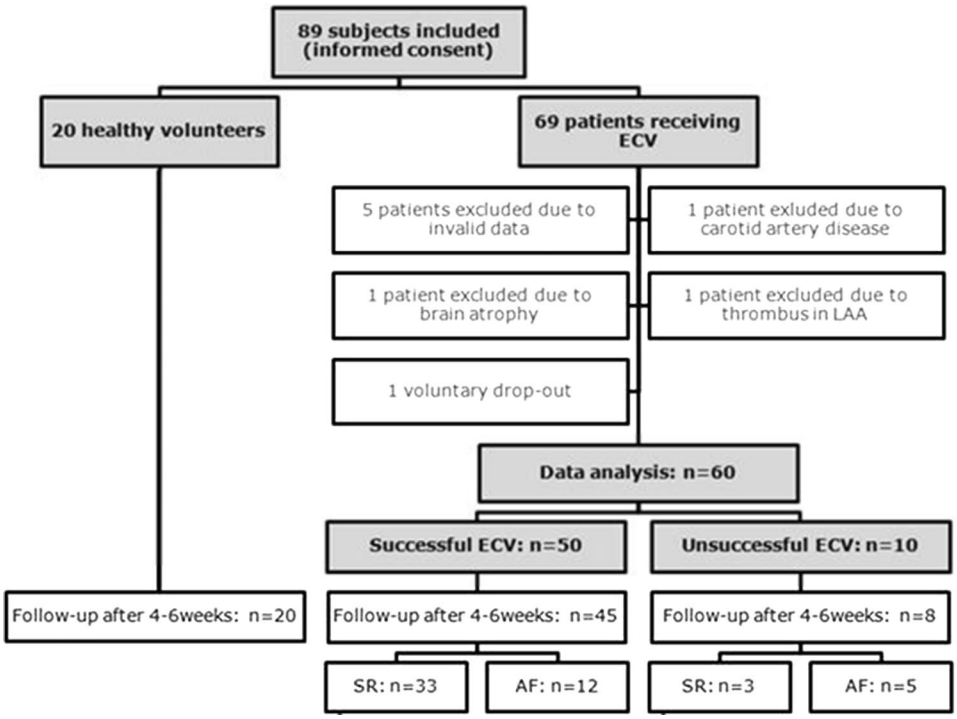

Fig. 1 Patient flowchart. *ECV* electrical direct current cardioversion, *LAA* left atrial appendage, *SR* sinus rhythm, *AF* atrial fibrillation

ECV and relapsed at follow-up, no significant differences in $SctO_2$ were observed.

3.2 Influences of unsuccessful electrical cardioversion on $SctO_2$

When ECV did not restore SR, no significant decrease after induction was observed (0.19% ± 6.84; p = 0.931). In these patients, no instant $SctO_2$ change after cardioversion was found (− 1% (− 5; 3); $p = 0.481$) with an observed maximal increase of 2% (− 1; 5) ($p = 0.287$). Four to six weeks after unsuccessful ECV (33 days [5; 38]), $SctO_2$ values were lower compared to baseline $SctO_2$ values ($p = 0.041$).

A negative correlation was found between the instant change in $SctO_2$ peri-ECV and the baseline $SctO_2$ ($R^2 = -0.279$; $p = 0.031$). The change in $SctO_2$ peri-ECV was related to the simultaneous change in MAP ($R^2 = 0.391$; $p = 0.004$) (Fig. 3). The change in $SctO_2$ was found to be independent of the duration of AF ($p = 0.412$), the baseline LVEF ($p = 0.480$), the administered dose of propofol (1.10 mg/kg) for sedation ($p = 0.440$) and heart rate ($p = 0.074$).

3.3 Influence of electrical cardioversion on quality of life and neuropsychological functioning

The entire neuropsychological test battery was completed by four AF patients with an unsuccessful ECV (40%), 19 AF patients with a successful ECV (38%) and 20 healthy volunteers who acted as controls (100%). The SF-36 questionnaire was completed twice by all subjects (mean interval of 35 days [30; 41]).

At baseline, no significant differences were found with regard to the baseline neuropsychological function and quality of life between the three groups. In contrast, the quality of life improved after successful ECV, whereas a trend towards a worsening after unsuccessful ECV was observed. More specifically, compared to the baseline status, significant differences between the groups were observed at follow-up with regard to the change in social functioning ($p < 0.001$), role limitations due to physical functioning ($p = 0.015$), mental health ($p = 0.002$), vitality ($p = 0.003$) and the short term change in health ($p = 0.021$) (Table 3). Patients with successful ECV described themselves as having more vitality, better physical and social functioning and having a better metal health at follow-up. The $SctO_2$ did not correlate with the patient's quality of life, except for physical functioning—i.e. walking, climbing stairs, etc. – ($R^2 = 0.230$; $p = 0.025$). Furthermore, no difference was observed in extensive neuropsychological functioning before ECV and at follow-up, independently if ECV was successful or not.

4 Discussion

In this study, we observed a significant increase in $SctO_2$ in AF patients after successful restoration of sinus rhythm. However, this increase was not long-lasting as this increase was absent at follow-up (4–6 weeks later) even if the data were excluded of the 12 patients who were back in AF at

Table 1 Baseline characteristics

	AF patients		Healthy volunteers (n = 20)	p value
	Successful ECV (n = 50)	Unsuccessful ECV (n = 10)		
Baseline characteristics				
Age (years)	67 [60; 73]	75 [70; 83]	68 [53; 81]	0.074
Male (%)	34 (68)	7 (70)	13 (65)	0.955
$SctO_2$ (%)	70 ± 6.28	69 ± 5.06	n.a	0.866
SpO_2 (%)	97 ± 2.70	97 ± 2.08	n.a	0.969
MAP (mmHg)	92 ± 13.33	95 ± 13.50	n.a	0.574
Heart rate (bpm)	89 ± 22.09	95 ± 22.31	n.a	0.485
Paroxysmal/persistent AF (%)	20/30 (40/60)	6/4 (60/40)	n.a	0.244
AF history (%)	30 (60)	5 (50)	2 (10)	**0.001***
Sedation during ECV				
Propofol 1% (mg/kg)	1.12 [0.85; 1.58]	1.16 [0.77; 1.65]	n.a	0.945
Comorbidities				
CVA/TIA	6 (12)	0 (0)	2 (10)	0.513
COPD				0.592
GOLD class I (%)	4 (8)	0 (0)	1 (5)	
GOLD class II (%)	2 (4)	1 (10)	0 (0)	
Diabetes mellitus (%)	8 (16)	2 (20)	2 (10)	0.731
Arterial hypertension (%)	23 (46)	6 (60)	6 (30)	0.258
Structural heart disease (%)	16 (32)	6 (60)	1 (5)	**0.005***
Ischemic heart disease (%)	13 (26)	6 (60)	3 (15)	**0.031***
Pacemaker/CRT (%)	7 (14)	1 (10)	0 (0)	0.211
Acute myocardial infarction (%)	3 (6)	2 (20)	0 (0)	0.102
Baseline medication				
Antiarrhythmica (%)	13 (26)	3 (30)	2 (10)	0.331
Beta blocker (%)	36 (72)	8 (80)	5 (25)	**0.001***
ACE-inhibitor (%)	25 (50)	4 (40)	6 (30)	0.372
Calcium-channel antagonist (%)	13 (26)	2 (20)	4 (20)	0.866
Statins (%)	20 (40)	6 (60)	3 (15)	**0.046***
LMWH (%)	9 (18)	2 (20)	1 (5)	0.379
Oral anticoagulants (%)	22 (44)	7 (70)	0 (0)	**0.001***
Aspirin (%)	18 (36)	5 (50)	5 (25)	0.444
Diuretics (%)	24 (48)	7 (70)	6 (30)	0.138

Data which follow a normal distribution are presented as mean ± standard deviation. When not normally distributed, data are presented as median and interquartile range [Q1; Q3]. Categorical data are presented as n (%)

AF atrial fibrillation, *ECV* electrical direct current cardioversion, *$SctO_2$* regional cerebral tissue oxygen saturation, *SpO_2* pulse oximetry, *MAP* mean arterial pressure, *bpm* beats per minute, *CVA* cerebrovascular accident, *TIA* transient ischemic attack, *COPD* chronic obstructive pulmonary disease, *CRT* cardiac resynchronization therapy, *ACE-inhibitor* angiotensin-converting-enzyme inhibitor, *LMWH* low molecular weight heparin, *n.a.* not available

Significant values are given in bold

*$p < 0.05$

follow-up. No immediate increase in $SctO_2$ was observed after ECV if sinus rhythm was not restored. An improvement in quality of life of the patients was observed after successful ECV, however, this was not correlated with $SctO_2$. Neuropsychological functioning of AF patients did not change after ECV even if sinus rhythm was restored.

Although it is well known that AF is accompanied by an increased risk to develop stroke and transient ischemic accident (TIA), it has recently emerged that AF is also associated with cognitive decline even without the presence of stroke, TIA or other risk factors [12]. Three potential mechanisms which might contribute to this decline are

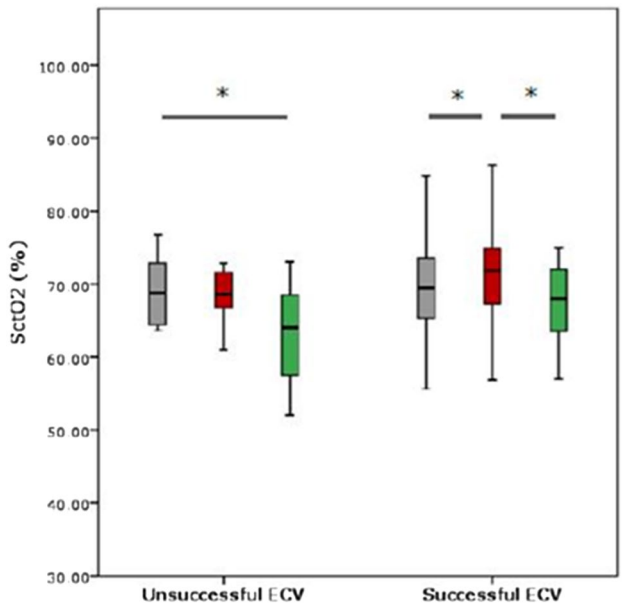

Fig. 2 Alterations in cerebral saturation amongst patients undergoing electrical cardioversion (ECV). A significant increase in $SctO_2$ was observed immediately after successful ECV (n = 50; red), but not after unsuccessful ECV (n = 10). At follow-up (green), 4 to 6 weeks after cardioversion, the $SctO_2$ values had returned to baseline levels (grey) in the successful ECV group and were even lower than baseline in patients with an unsuccessful ECV. *p < 0.05

Table 2 Cerebral saturation values

	Successful ECV	Unsuccessful ECV
Baseline	69% ± 6	69% ± 5
Prior to ECV	70% ± 6	69% ± 5
Post-ECV	71% ± 6	68% ± 4
Follow-up	68% ± 5	63% ± 8

Baseline, before and after electrical cardioversion regional cerebral saturation values ($SctO_2$)

ECV electrical direct current cardioversion

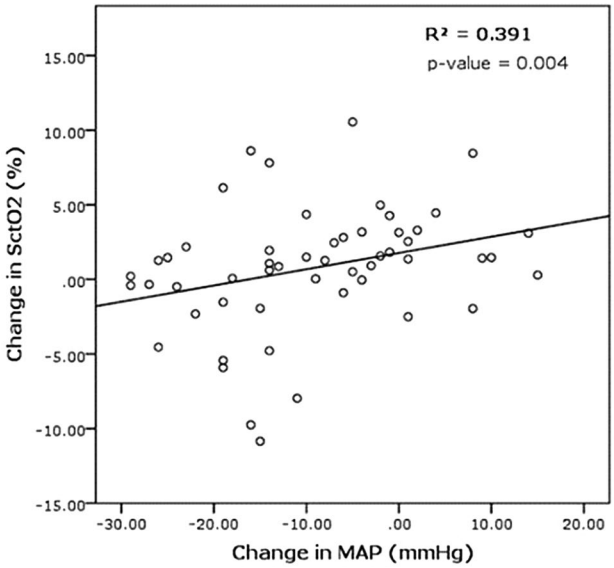

Fig. 3 The instant change in $SctO_2$ in function of the change in mean arterial pressure (MAP). A significant correlation was found ($R^2 = 0.391$; $p = 0.004$)

silent cerebral ischemia, inflammation and altered cerebral blood flow (CBF) [15]. Specifically, AF induces a beat-to beat variability in cardiac output (CO) as it eliminates the atrial component of CO which induces a reduction in CBF [15]. This reduction in CBF is even more pronounced if a rapid ventricular rate is present, especially in the frontal superior region of the brain [16]. Moreover, Efimova et al. demonstrated that cerebral perfusion and cognitive brain function improved after AV node ablation and pacemaker implantation in AF patients with rapid ventricular rate [16]. However, others showed a normal mean CBF in AF patients probably due to intact cerebral autoregulation, but higher variability in the smaller capillaries and arterioles resulting in local hypoperfusion dependent from beat to beat [17].

Using NIRS technology, frontal $SctO_2$ is measured at the level of capillaries and arterioles which is the area of interest to measure frontal cerebral hypoperfusion during AF and the influence of a successful ECV on $SctO_2$.

This study confirmed that a successful ECV was associated with an immediate increase in $SctO_2$ while no change or even a decrease in $SctO_2$ was observed when sinus rhythm was not restored [8]. Interestingly, in those twelve patients who were back in AF at follow-up, this change in $SctO_2$ immediately after ECV remained absent as well. One explanation for the increase in $SctO_2$ after successful ECV is a sudden increase in CO which is positively associated with $SctO_2$ [18, 19]. This finding might be explained by the resynchronization of the atria and the ventricles leading to the retrieval of the atrial booster pump function (atrial kick) and the prevention of atrioventricular valve regurgitation [20]. Moreover, during defibrillation threshold analyses, a similar course of $SctO_2$ was observed with an excessive increase after successful defibrillation [21]. However, it has to be admitted that the increase in $SctO_2$ in patients with a successful ECV might be considered too small to likely represent any clinically important outcome.

To date, it is unknown whether this observed increase in $SctO_2$ after successful ECV is persisting. Therefore, we measured $SctO_2$ 4 to 6 weeks after successful ECV. At follow-up, the measured $SctO_2$ was similar to the baseline $SctO_2$ obtained prior to ECV. Even if the twelve patients were excluded who were relapsed into AF, baseline $SctO_2$ was similar to $SctO_2$ measured at follow-up. If we assume that the instant increase in $SctO_2$ is caused by

Table 3 Change in the scale scores for quality of life and neuropsychological functioning

	AF patients		Healthy volunteers	p value
	Successful ECV	Unsuccessful ECV		
Quality of life[a]				
Physical functioning (%)	5.00 [− 10.00; 25.00]	− 15.00 [− 42.50; 5.00]	0.00 [− 5.00; 8.75]	0.077
Social functioning (%)	0.00 [0.00; 11.11]	− 22.00 [− 50.00; 0.00]	0.00 [− 8.33; 0.00]	< 0.001
Role limitations (physical) (%)	0.00 [0.00; 50.00]	0.00 [− 75.00; 0.00]	0.00 [0.00; 0.00]	0.015
Role limitations (emotional) (%)	0.00 [− 33.00; 33.33]	0.00 [− 100.00; 0.00]	0.00 [0.00; 0.00]	0.165
Mental health (%)	4.00 [0.00; 16.00]	− 4.00 [− 20.00; 0.00]	0.00 [− 10.33; 3.00]	0.002
Vitality (%)	15.00 [− 5.00; 25.00]	− 15.00 [− 22.50; 2.50]	0.00 [− 5.00; 5.00]	0.003
Pain (%)	0.00 [0.00; 22.45]	0.00 [0.00; 5.10]	0.00 [− 11.74; 10.20]	0.346
General health (%)	0.00 [− 15.00; 15.00]	− 5.00 [− 32.50; 2.50]	− 2.50 [− 8.75; 5.00]	0.411
Change in health (%)	25.00 [0.00; 50.00]	25.00 [− 37.50; 50.00]	0.00 [0.00; 0.00]	0.021
Neuropsychological functioning[b]				
AVLT (ΔN)	− 7.00 [− 15.00; 2.50]	5.00 [3.00; 8.50]	2.50 [− 3.75; 6.50]	0.011
MMSE (Δ./30)	1.00 [− 0.25; 4.00]	− 0.50 [− 1.00; 0.00]	0.00 [− 0.88; 1.00]	0.040
Trail making part A (Δs)	− 3.00 [− 12.00; 4.00]	− 12.00 [− 18.25; − 3.50]	− 7.00 [− 16.00; 4.00]	0.289
Trail making part B (Δs)	− 17.00 [− 40.00; − 2.25]	− 40.00 [− 82.25; − 6.00]	− 20.00 [− 56.00; − 5.00]	0.733
Symbol coding (ΔN/2 min)	7.50 [3.50; 13.00]	9.00 [1.00; 9.00]	5.00 [− 1.00; 9.00]	0.316

Data are presented as median and interquartile range [Q1; Q3]

AF atrial fibrillation, *ECV* electrical cardioversion, *AVLT* (Δ*N*) auditory verbal learning test (change in the number of recalled words), *MMSE* (Δ./30) mini-mental state examination (change in the obtained score, with a maximum score of 30), Δ*s* change in the seconds needed to complete the test part, *Symbol coding* (Δ*N/2 min*) Wechsler digit-symbol coding (change in the amount of decoded digits within a time span of 2 min

[a]Quality of life data were available for 60 AF patients (50 patients with a successful electrical cardioversion and ten patients with an unsuccessful cardioversion) and twenty age- and gender-matched healthy volunteers. The higher the percentage score, the better

[b]Neuropsychological functioning was assessed in four AF patients with an unsuccessful electrical cardioversion (40%), nineteen AF patients with a successful cardioversion (38%) and twenty healthy volunteers (100%)

an improvement of CO successful ECV, return of $SctO_2$ towards baseline values at follow-up might be explained by a decrease in CO as well or by a delayed activation of cerebral autoregulation. In the latter case, the cerebral autoregulation mechanisms were assumed to be transiently stunned by the sudden increase in CO after successful ECV. The significant observed correlation between the change in $SctO_2$ and the change in MAP suggests that alterations in blood pressure might underlie the observed changes in $SctO_2$ during ECV and implicate a potentially acute disturbed cerebral autoregulation. However, others reported no or a delayed influence of ECV on CO [22, 23]. Our observations seem to confirm that $SctO_2$ follows hemodynamic changes induced by ECV itself and restoration of sinus rhythm [24].

In general, AF patients were not feeling ill or restricted in their daily activities as a result of their cardiac arrhythmia. Nevertheless, the quality of life of patients with a successful ECV was improved at follow-up compared to the baseline assessment prior to ECV. The main improvements were observed amongst social functioning, mental health and vitality, which might demonstrate that patients were mentally reassured after the successful treatment. Since AF has been linked with mild cognitive impairment and dementia, an assessment of neuropsychological functioning on a long term (e.g. 3 months, 6 months, 1 year) might be interesting [2, 3]. In this study, a second implementation of the test battery at 1 month was elected in the current study after consideration of the learning effects and drop-out levels. No difference between AF patients and healthy volunteers was observed in neuropsychological function nor a significant improvement regarding the neuropsychological function of patients with a successful ECV. In our study, follow-up was scheduled 1 month after ECV. Probably this time frame is too short to observe any differences as others observed an improvement on longer term [25].

5 Study limitations

The current study was a monocenter trial with a limited sample size. Larger studies with a longitudinal design and multiple repeated measurements of $SctO_2$ would be interesting in order to confirm our observed changes in $SctO_2$ in both patient groups, also at follow-up. Secondly, the change in $SctO_2$ in patients with a successful ECV might be considered too small to likely represent any clinically

important outcome. In fact, it is also possible that this change was induced by the administration of oxygen. The latter remains unknown as no $SctO_2$ was measured in the healthy volunteers. Third, (non-) invasive monitoring of CO and arterial carbon dioxide would be of interest to gain knowledge about the influence of both parameters on the observed results. Fourth, only a limited different brain areas were involved in the neurophysiological test battery. Nevertheless, we constructed an overall assessment of neuropsychological functioning by using a limited amount of tests in order to reduce the performance time, keeping in mind the limited time span between the arrival of the ambulatory AF patients at the chest pain unit and the execution of the ECV. Despite the use of a limited number of tests to reduce performance time, the number of patients who completed the whole neuropsychological test battery was low. This was due to the limited time available between arrival of the patient at the hospital and the ECV, as all ECV procedures were performed in an ambulatory setting. Finally, the current study exclusively dealt with ECV as a rhythm control strategy for AF. The observed effects might be inherent to the treatment strategy (ECV), instead to the conversion of AF towards a regular sinus rhythm. Additional, longitudinal research in AF patients receiving a pharmacological rhythm control treatment will be of interest to clarify whether the effects on $SctO_2$, quality of life (and neuropsychological functioning) are inherent to the treatment strategy or to rhythm control in general. Unfortunately we do not have any data about change in negative inotropic drugs or β-blocker administration. However we can only assume that the treatment did not change after ECV in the unsuccessful ECV group as the patients were already treated with a rate control strategy.

6 Conclusion

The current study confirmed an instant increase in $SctO_2$ after successful ECV, though the increase was small and not long-lasting. This temporary increase in $SctO_2$ did not influence the neuropsychological functioning of the patients. However, it has to be admitted that the increase in $SctO_2$ in patients with a successful ECV might be considered too small to likely represent any clinically important outcome Furthermore, it was found that successful ECV does not exert beneficial effects on the patient's neuropsychological function, 1 month after ECV.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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