Quantitative EEG Changes in Carotid Endarterectomy Correlated with Ischemia

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I. INTRODUCTION

Continuous intraoperative monitoring with electroencephalography (EEG) is routinely used in carotid endarterectomy (CEA) to detect cerebral ischemia [1]. Visually observed changes in EEG related to ischemia include an ipsilateral decrease in amplitude of faster frequencies or an ipsilateral increase in activity of slower frequencies. In the literature, significant EEG change has been defined as a decrease in the amplitude in the alpha frequency band by 50% or greater or an increase in activity in the theta or delta frequency band by 50% or greater [2, 3]. Compared to raw EEG, quantitative EEG (QEEG) parameters can enhance visual EEG review. QEEG parameters are derived by applying Fourier transformation to raw EEG signals to generate power spectra [4]. Examples of QEEG parameters include delta, theta, alpha, beta, gamma power values, alpha power to delta power ratio (ADR), beta power to delta power ratio (BDR), alpha-plus-beta power to delta-plus-theta power ratio (ABDTR), spectral edge frequency 90% (SEF90) and amplitude-integrated EEG (aEEG). QEEG parameters have been previously investigated in detecting ischemia in a relatively small number of patients undergoing CEA [5]. In this study, we report on the analyses of QEEG parameters in a large population of patients who underwent CEA with EEG monitoring.

II. METHODS

We obtained intraoperative EEG recordings on 1,551 patients who underwent CEA in the years 2009 to 2017 in UPMC hospitals in Pittsburgh. All EEG recordings captured eight channels: F3-P3, P3-O1, F3-T3, T3-O1, F4-P4, P4-O2, F4-T4, and T4-O2. A neuromonitoring expert annotated the time periods indicative of ischemia in each recording. From each recording, we extracted 10 minutes of post-clamp EEG signal for analysis. After applying low-pass (70Hz), high-pass (0.166Hz), and notch (60Hz) filters, each 10-minute recording was partitioned into 20-second intervals. We applied SciPy's signal.spectrogram method for computing Fourier Transforms for the QEEG features delta, theta, alpha, beta, gamma power values, ADR, BDR, and ABDTR. We used 20-second intervals since, in future work, we plan to use these features for the automated detection of cerebral ischemia, and we determined that producing a prediction every 20 seconds is clinically optimal. Furthermore, changes in cerebral blood flow can take up to 20 seconds to be clearly reflected on EEG recordings. For each 20-second interval, we calculated two sets of the following QEEG parameters for each side of the brain (ipsilateral and contralateral to the side of surgery): normalized delta, theta, alpha, beta, gamma power values averaged over four channels of each side of the brain, and corresponding ADR, BDR, ABDTR, SEF90, and aEEG values. QEEG parameters were calculated from each 20-second post-clamp interval and normalized using a 120-second baseline EEG recorded before carotid clamping to produce z-scores. We found that a 120-second baseline EEG with minimal noise and variance was sufficient to estimate the parameters of the baseline distribution.

From the 10-minute recording for each patient, a peak value and a trough value were identified for each QEEG parameter as the maximum value and minimum value, respectively, that were observed during the 10 minutes. We used the nonparametric Mann-Whitney U test to identify QEEG parameters that were statistically significantly different between the ischemic-change and no-ischemic-change intervals as determined by the expert-assessed time periods of ischemic EEG change.

Table 1. Comparison of z-scores of ipsilateral QEEG parameters in the ischemic-change versus no-ischemic-change groups

QEEG Parameter	Ischemic-Change Group (n=84)	No-Ischemic-Change Group (n=1459)	P-value
Delta			
Trough, median	-2.10	-0.97	**<0.001**
Peak, median	+0.78	+0.90	0.091
Theta			
Trough, median	-2.16	-0.47	**<0.001**
Peak, median	+0.37	+0.85	**<0.001**
Alpha			
Trough, median	-3.12	-0.75	**<0.001**
Peak, median	+0.18	+0.68	**<0.001**
Beta			
Trough, median	-2.57	-0.71	**<0.001**
Peak, median	+0.29	+0.84	**<0.001**
Gamma			
Trough, median	-1.35	-0.62	**<0.001**
Peak, median	+1.22	+1.54	**0.019**
ADR			
Trough, median	-2.06	-0.80	**<0.001**
Peak, median	+0.68	+0.85	**0.004**
BDR			
Trough, median	-1.62	-0.77	**<0.001**
Peak, median	+0.70	+0.89	**0.003**
ABDTR			
Trough, median	-1.83	-0.88	**<0.001**
Peak, median	+0.46	+0.72	**0.003**
SEF90			
Trough, median	-1.56	-0.69	**<0.001**
Peak, median	+0.79	+1.00	**0.017**
aEEG			
Trough, median	-1.52	-0.55	**<0.001**
Peak, median	+0.51	+1.02	**0.011**

III. RESULTS

Table 1 compares z-scores for ten ipsilateral QEEG parameters in the ischemic-change versus no-ischemic-change groups. Overall, both median trough and median peak z-scores were decreased in the ischemic-change group compared to the no-ischemic-change group. Mann-Whitney U test results show that the median trough for every QEEG z-score was statistically significantly lower in the ischemic-change group compared to the no-ischemic-change group ($p<0.05$). On the other hand, the median peak z-score was statistically significantly lower in the ischemic-change group compared to the no-ischemic-change group ($p<0.05$) for nine of the ten QEEG parameters, except for the delta parameter.

Table 2 shows the results for the contralateral QEEG parameters. Overall, both median trough and median peak z-scores were decreased in the ischemic-change group compared to the no-ischemic-change group. However, compared to the ipsilateral parameters, the contralateral parameters are decreased to a lesser extent. The median trough z-score was statistically significantly lower in the ischemic group compared to the no-ischemic group ($p<0.05$) for all ten QEEG parameters. And the median peak z-score was statistically significantly lower in the ischemic group compared to the no-ischemic group ($p<0.05$) for only four QEEG parameters, except for the delta, gamma, BDR, ABDTR, SEF90, and aEEG parameters.

Our results indicate that compared to baseline, decreases in QEEG parameters due to ischemia are more pronounced in trough values over peak values and more pronounced on the side of the surgery over the contralateral side. These results confirm prior studies reported in the literature [5].

Table 2. Comparison of z-scores of contralateral QEEG parameters in the ischemic-change versus no-ischemic-change groups

QEEG Parameter	Ischemic-Change Group (n=84)	No-Ischemic-Change Group (n=1459)	P-value
Delta			
Trough, median	-1.19	-0.92	**<0.001**
Peak, median	+0.72	+0.96	0.305
Theta			
Trough, median	-0.91	-0.45	**<0.001**
Peak, median	+0.60	+0.95	**0.003**
Alpha			
Trough, median	-1.39	-0.73	**<0.001**
Peak, median	+0.33	+0.75	**<0.001**
Beta			
Trough, median	-1.16	-0.65	**<0.001**
Peak, median	+0.52	+0.85	**0.001**
Gamma			
Trough, median	-0.89	-0.59	**<0.001**
Peak, median	+1.12	+1.45	0.073
ADR			
Trough, median	-1.31	-0.86	**<0.001**
Peak, median	+0.69	+0.85	**0.018**
BDR			
Trough, median	-1.08	-0.72	**0.008**
Peak, median	+0.80	+0.88	0.193
ABDTR			
Trough, median	-1.24	-0.86	**0.002**
Peak, median	+0.58	+0.72	0.056
SEF90			
Trough, median	-1.09	-0.70	**0.007**
Peak, median	+0.96	+0.98	0.148
aEEG			
Trough, median	-0.89	-0.53	**<0.001**
Peak, median	+0.82	+0.97	0.093

IV. FUTURE WORK

In the future, we plan to investigate the QEEG parameters reported here to develop machine learning detection algorithms to reliably predict cerebral ischemia and evaluate the performance of the algorithms on an independent dataset.

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Introduction

- Continuous intraoperative monitoring with electroencephalography (EEG) is routinely used in carotid endarterectomy (CEA) to detect cerebral ischemia
- Ischemia associated with ipsilateral decrease in amplitude of faster frequencies or ipsilateral increase in activity of slower frequencies
- Significant EEG change defined as 50% or greater or an increase in activity in the theta or delta frequency band by 50% or greater
- QEEG parameters include delta, theta, alpha, beta, gamma power values, alpha power to delta power ratio (ADR), beta power to delta power ratio (BDR), alpha-plus-beta power to delta-plus-theta power ratio (ABDTR), spectral edge frequency 90% (SEF90) and amplitude-integrated EEG (aEEG)
- QEEG parameters derived from Fourier transformations of raw EEG signals
- Analyses of QEEG parameters in large population of patients who underwent CEA with EEG monitoring

Population Statistics

- Intraoperative EEG recordings of CEA patients
- 1551 patients who underwent CEA from 2009 to 2017 in UPMC hospitals in Pittsburgh
- Eight Channels captured for each patient F3-P3, P3-O1, F3-T3, T3-O1, F4-P4, P4-O2, F4-T4, and T4-O2

Methods

- 10 minutes of post-clamp EEG signal for analysis
- Applied low-pass (70Hz), high-pass (0.166Hz), and notch (60Hz) filters, each 10-minute recording was partitioned into 20-second intervals
- SciPy's signal.spectrogram method for computing Fourier Transforms for the QEEG features delta, theta, alpha, beta, gamma power values, ADR, BDR, and ABDTR
- We used 20-second intervals since, in future work, we plan to use these features for the automated detection of cerebral ischemia, and we determined that producing a prediction every 20 seconds is clinically optimal.
- Furthermore, clinically relevant changes in cerebral blood flow can take up to 20 seconds to be clearly reflected on EEG recordings.
- For each 20-second interval, two sets of the following QEEG parameters for each side of the brain (ipsilateral and contralateral to the side of surgery): normalized delta, theta, alpha, beta, gamma power values averaged over four channels of each side of the brain, and corresponding ADR, BDR, ABDTR, SEF90, and aEEG values.
- QEEG parameters were calculated from each 20-second post-clamp interval and normalized using a 120-second baseline EEG recorded before carotid clamping to produce z-scores
- 10-minute recording for each patient, a peak value and a trough value were identified for each QEEG parameter as the maximum value and minimum value, respectively, that were observed during the 10 minutes.

Methods (Continued)

- Nonparametric Mann-Whitney U test to identify QEEG parameters that were statistically significantly different between the ischemic-change and no-ischemic-change intervals as determined by the expert-assessed time periods of ischemic EEG change

Results

- Overall, both median trough and median peak z-scores were decreased in the ischemic-change group compared to the no-ischemic-change group for ipsilateral QEEG parameters.
- Median trough for every QEEG z-score was statistically significantly lower in the ischemic-change group compared to the no-ischemic-change group (p<0.05)
- Median peak z-score was statistically significantly lower in the ischemic-change group compared to the no-ischemic-change group (p<0.05) for nine of the ten QEEG parameters, except for the delta parameter

Table 1. Comparison of z-scores of ipsilateral QEEG parameters in the ischemic-change versus no-ischemic-change groups

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Trough, median	-1.52	-0.55	**<0.001**
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- Overall, both median trough and median peak z-scores were decreased in the ischemic-change group compared to the no-ischemic-change group.
- The median trough z-score was statistically significantly lower in the ischemic group compared to the no-ischemic group (p<0.05) for all ten QEEG parameters.
- The median peak z-score was statistically significantly lower in the ischemic group compared to the no-ischemic group (p<0.05) for only four QEEG parameters, except for the delta, gamma, BDR, ABDTR, SEF90, and aEEG parameters.
- Our results indicate that compared to baseline, decreases in QEEG parameters due to ischemia are more pronounced in trough values over peak values and more pronounced on the side of the surgery over the contralateral side. These results confirm prior studies reported in the literature

Results (Continued)

Table 2. Comparison of z-scores of contralateral QEEG parameters in the ischemic-change versus no-ischemic-change groups

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Trough, median	-0.89	-0.53	**<0.001**
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Conclusion

- Our results indicate that compared to baseline, decreases in QEEG parameters due to ischemia are more pronounced in trough values over peak values and more pronounced on the side of the surgery over the contralateral side. These results confirm prior studies reported in the literature

Future Works

- In the future, we plan to investigate the QEEG parameters reported here to develop machine learning detection algorithms to reliably predict cerebral ischemia and evaluate the performance of the algorithms on an independent dataset.

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