Cerebral Vascular accidents remain one of major causes of die and handicap the most frequently met in occidental countries. These ones are often associated to emboli transit, foreign bodies to blood normal composition, in cerebral circulation. Emboli number, nature are also directly related to a pathological degree. It seems obvious that a good emboli detection needs rejection of artifacts, which are undesirable events. The aim of this work is to proceed different artifact Doppler signals and to introduce a priori and a posteriori parameters which are able to characterize them at best. We discuss about their reliability for artifact rejection.

Corpus Establishment

We have created an artifacts corpus covering the most met clinical situations. These ones were acquired using to two ATYS medical devices: a 2 MHz two sample gates PW system and a two emission frequencies 1.66 and 2.5 MHz PW one. The sample volume is located in the middle cerebral artery at a depth of 46 mm, with a gate of 4 mm and a 100 mWcm$^{-2}$ emission power. This set-up has been conserved at best, specially insonification angle for all the different types of artifacts, which are: probe tapping, speak, sneeze, cough, sigh, gnashing, laugh, sniff, wink, yawn.

Signals analysis and parameter extraction

The first investigations were performed with a single emission frequency. The signals have been, thus, proceeded off-line and frequency, energy, and duration parameters were computed. Concerning frequency parameters, we compute three estimators (modal, centroid, and maximal frequencies).

For this, consider the spectrum $S(f)$ obtained on a 25 ms temporal window around artifact occurrence. Modal $f_{mod}$, centroid $f_c$, and maximal $f_{max}$ are, respectively, given by the expressions (1),(2), and (3) and relevant results are shown on figures (1),(2),(3). These figures show the (above) frequency estimators values with corresponding standard deviations, for each artifact type, estimated using the two signals obtain in the two sample volumes.

$$f_{mod} = \arg \max_f (S(f))$$

$$f_c = \frac{\int_0^{f_e} f S(f) df}{\int_0^{f_e} S(f) df}$$

$$f_{max} = f_c + B/2$$

$f_e$ is the sampling frequency, and $B$ is the $-6dB$ bandwidth.

We can remark that modal and centroid frequencies means (figure 1 and figure 2) are confined in the same range (100-250 Hz), but centroid frequencies values have highest standard deviations. Maximal frequencies (figure 3) can reach about 650 Hz, with important standard deviations between each artifacts type. Moreover, these frequencies are independent of artifact occurrence.
in cardiac cycle (diastolic or systolic times) and, especially the modal ones have very low values unlike emboli supposed to travel at the red blood cells (RBC) background speed. The results of the two gates are similar in terms of these estimators.

Concerning energy parameters, we introduced two estimators called ANR (Artifact to Noise Ratio) and ABR (Artifact to Blood Ratio). These ones can be expressed by equations (4), (5).

\[
ANR = 10 \log_{10} \left( \frac{P_{art}}{P_{noise}} \right)
\]

\[
ABR = 10 \log_{10} \left( \frac{P_{art}}{P_{blood}} \right)
\]

It can be noticed in figure (4) that ANR values are between 30 and 62 dB; indeed this criteria is essentially based on the bidirectional property of almost artifacts. ABR values, figure (5), are confined between 17 and 35 dB. These last ones can be compared to EBR (Embolus to Blood powers Ratio) [3]. These values are at far greater than the ones found, when micro-emboli are encountered.

Finally, we computed a duration-like parameter. For this, sample volume length (SVL) [4] values are used, and are expressed by equation (6). 

\[
SV L_{max} = \tau \cdot v_{max}
\]

\(\tau\) is event duration. In case of a moving embolus, SVL is defined as an effective sample volume length, which is directly function of embolus transit time and its associated speed. Embolus transit time is included between 10 and 200 ms with a 4mm gate and with a speed range from 0.02 to 0.4 \(m/s\). We can see, in figure (6), that SVL means can reach 90 mm for sigh or speaking, which are no more related to physical features. However, in case of probe tapping or gnashing, SVL means
are around 4mm. The sample volumes used were two gates distant of one gate, so we can determine, for each artifact types, time delays between their occurrences in proximal and distal gates. Maximal and minimal values obtained are shown in the figure(7). These values don’t exceed at best 1 ms, whereas they are, in case of emboli, confined between 10 and 350 ms in our experimental condition. This time delay estimator could thus be an interesting parameter for artifact rejection. Nevertheless, it may be erroneous in case of multiple emboli, or when the sample gates are short compared to embolus velocity.

**Observations**

Usually people dealing with emboli detection assume that all artifacts are bidirectional in Doppler spectrum. We can show in figure(8) that it isn’t always true. This may be explained as follows. It is known that RF backscattered signal is a mixing of the component reflected by immobile tissues (which is the DC component after demodulation), the one backscattered by RBC’s moving, and finally the one associated to vessel walls motion. In normal conditions, after in-phase and quadrature demodulation and high-pass filtering, it remains only Doppler spectrum caused by RBC’s transit. Artifact apparitions induce frequency transposition of each components of the whole RF spectrum. This is be due to stationary media put in moving by probe’s relative displacement. Figures (9) and (10) detailed several cases met following probe’s displacement direction.

**Figure 8:** Temporal signal and spectral contents of an unidirectional laugh artifact. **Figure 9:** Frequency transposition of the Doppler spectrum: bidirectional artifact. **Figure 10:** Frequency transposition of the Doppler spectrum: unidirectional artifact.
remarked that frequency components due to intermediate tissues or wall motion are always here in Doppler spectrum after demodulation and high-pass filtering. All these components have positive values, and are in forward flow. It is clearly an unidirectional artifact situation.

Signals analysis with the two emission frequencies device
The artifacts corpus is the same as previously, excepted it was acquired with the two emission frequencies 1.66 MHz and 2.5 MHz device. We compute a modal frequencies ratio as follows.

$$R = \frac{f_{mod_{1.66 MHz}}}{f_{mod_{2.5 MHz}}}$$

In case of an embolus crossing in sample volume, we could recover the same ratio that emission frequencies one, so \(\frac{2}{1}\). We computed this ratio for artifact events. In figure(11), it can be noticed that we don’t have any more the same ratio, and moreover this ratio tends to 1 for each type of artifact. It seems that these frequencies are independent of emission frequency. Therefore, this is due to the fact that the probe movement is asynchronous and depends only on the probe's speed. Artifacts may be observed even in absence of scatterers movement or in presence of 90° Doppler angle. Deeper investigations of this phenomenon is now being carrying on.

Discussion
We have reviewed several frequency, energy, temporal parameters in order to characterize artifact signatures in Doppler signal. Reliable parameters are mainly modal frequencies, which are very low and independent of cardiac cycle time, SVL and ABR. In combining these ones, it could be possible to obtain a reliable artifact rejection without necessary use a multigate system. We have seen that \textit{a priori} artifacts rejection based to the bidirectionality of the signal can be wrong. In case of use of a two emission frequencies PW system, a reliable artifact rejection can be reached in performing modal artifact frequencies ratio.

References