

Colloid Vibration Potential Imaging for Medicine.

Fria Hossein*, Mi Wang

School of Chemical and Processes Engineering, University of Leeds, UK

Abstract

Colloid vibration potential Imaging (CVPI) refers to the signal generated from the vibration of nanoparticles or ions in electrolyte (or tissue), which has a fundamental difference from the conventional ultrasound reflection detection (URD) based imaging technology. In this paper we demonstrate the super capability of CVP signal (or as one dimensional imaging) over the conventional ultrasound imaging. Pork meats were selected and examined with our current CVP instrumentations, and also the conventional ultrasound reflection detection (URD) (Panametrics 5072PR). The additional signatures of CVP measured within the sample/pork reveals the specific physicochemical structures of tissue which the conventional ultrasound technique cannot see. The results, with pervious findings, further support the potential of CVP for providing new and/or complementary knowledge for medicine diagnose and research.

Keywords: Colloid vibration potential imaging, Ultrasound, Medicine, Nanoparticles, Electrolytes, Tissue.

Accepted on 16 December, 2019

Introduction

The science behind ultrasound can be traced back to Lazzaro Spallanzani [1], who demonstrated that bats can navigate by inaudible sound. Diagnostic ultrasound within the field of medicine was first used by Karl Dussik in 1942 [2], and later, George Ludwig used ultrasound to study gallstones [3]. Ultrasound diagnostic imaging is an imaging technique that can be used to visualize the size and structure of the internal organs of the human body. The principle is that a high-frequency sound wave (typically, 1-6 MHz) is sent through the body by using a probe (transducer). The distances and sizes of the organs can be calculated by the speed of the sound wave through the body, and by the arrival time of the signal. The choice of frequency used can be for high-resolution imaging of for deeper, penetrative imaging.

The concept of ion vibration potential (IVP) for ionic electrolytes dates back to Debye (1933) [4]. The first report on CVP was made by Hermans in 1938 [5], followed by other researchers Rutgers and Rigole in 1957 [6]. The theory of CVP of dilute solutions was first presented by Booth and Enderby in 1952 [7], while early experimental work on colloidal suspensions was conducted by Zana and Yeager (1967) [8].

O'Brien (1987) then developed a model which explained the electric potential generated by the sound wave in colloidal suspensions (O'Brien, 1987). The analytical expressions for both IVP and CVP derived by Ohshima and Dukhin in 1999 [9]. There has also been speculative and experimental work carried out in this field by both Brown University (Vitalyi and Diebold, 2005) and the University of Leeds (Guang et al., 2011). A new UVP testing phantom made from agar, and called the Leeds standard III UVP device for UVP imaging, has been designed, in which electrodes are non-intrusively attached to the body, presented by Hossein and Wang (2019) [10].

This report is to investigate whether CVP signal can be measurable, and the feasibility to be developed as a new functional imaging for medicine diagnose and research. It simplify the approach, pork meats were selected and examined with our current CVP instrumentation and also the conventional ultrasound reflection detection (URD) (Panametrics 5072PR). The discovery of new finding would present specific tissue structures by comparing images of these three modes of tissue information: specified as being ionic vibration based, ultrasound impedance reflection intensity based, and conductivity distribution-based tissue information.

Experiment

The pork meats were bought from a butcher shop in Leeds Kirkgate Market. The meats prepared for the test were cut into a cuboid shape with dimensions. The meat samples consisted of muscle only (M), muscle with fat (MF), and muscle with fat and skin (MFS), small bone with muscle (SMB), and large bone with muscle (LMB). These samples were kept in a fridge at a temperature of 3 for 24 hours before the test. The specific type of tissue (pork tissue) containing sufficient electrolytes (or ionic fluids) and having a difference in physicochemical properties, which might generate a high CVP signal, were preselected for the test (Table 1).

Table 1. The specific description of the selected samples. The samples were cut with a sharp knife to give a shape that could easily fit into all the vessels to be used for the test.

Sample Name	Description	Size (mm) ³	Animal Product
M	Muscle	58 × 28 × 45	Pork
MF	Muscle with fat	55 × 50 × 46	Pork

The internal thickness (1): $x_3 = 4.29$ mm

The interior thickness (2): $x_4 = 4.44$ mm

The inner 1 and inner 2 indicates a small layer of fat inside the muscle when anatomically viewed.

Test 1: URD: Sample (M)

The same sample (M) was left inside the UVP standard II testing device. The transducer was connected to an ultrasound pulser/receiver with a gain factor of 39 dB. The URD signal measurement is shown in figure 5.

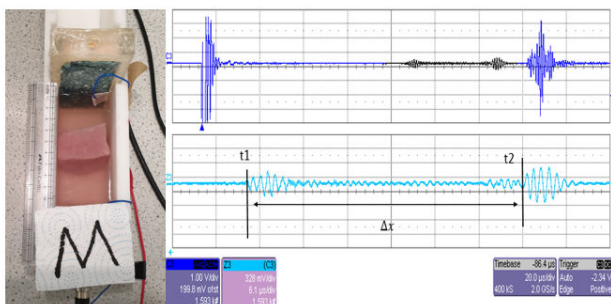


Figure 5. Ultrasound reflection detection for sample (M). The first reflected signal appeared at $t_1=98.5 \mu s$ and $t_2=134.43 \mu s$, and the sample thickness measured at $\Delta x = 25.47$ mm.

Both imaging tests were carried out using the same sample (M). Four signals were detected inside the sample (M) using the CVP method and only two signals appeared using the URD method. The inside of the sample (M) contains two small layers of fat; this feature was detected by the CVP method while the other method was not able to detect this. The sample thickness was measured as $\Delta x = 25.01$ mm in the CVP imaging and $\Delta x = 25.47$ mm in the ultrasound imaging.

Test 2: CVPI: Sample (MF)

A large piece of pork muscle with fat (MF) was placed inside the testing rig. The sample was placed 33 mm away from the transducer interface. The eight bursts of CVP signals were generated by the sample (MF) and measured by both electrodes. The signals were amplified by the voltage amplifier with an amplification factor of 39 dB. The measured signal was displayed on the oscilloscope and the image is presented in Figure 6.

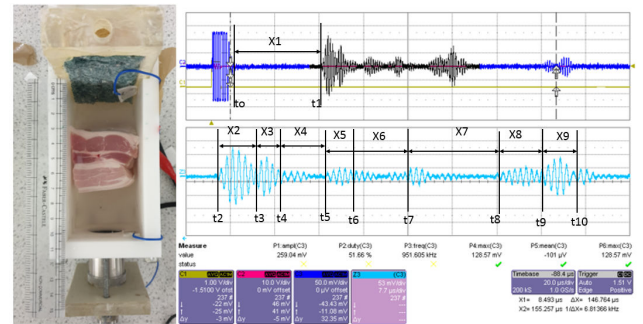


Figure 6. CVP measured from sample (MF).

Figure 6 shows the CVP signal measured for the sample (MF). Eight bursts of CVP signal were measured from the sample. From the detected signals, the first burst and the second burst appear to be mixed due to the frequency issue and thickness of the layer, and the fifth and sixth signals are also mixed due to the same problem. This sample contains multilayer fat and muscles.

$x_1=32.5$ mm, $x_2=5.55$ mm, $x_3=2.77$ mm, $x_4=5.698$ mm, $x_5=3.988$ mm, $x_6=6.837$ mm, $x_7=11.396$ mm, $x_8=5.698$ mm, $x_9=4.55$ mm

The thickness of the sample measured at $\Delta x = 46.479$ mm. the measured values are the distance between the first boundary of the sample and the transducer interface into water.

Test 2: URD: Sample (MF)

The same sample (MF) was left inside the UVP standard II testing device. The transducer was connected to an ultrasound pulser/receiver with a gain factor of 39 dB. The ultrasound pulses were sent through the water tank via the same transducer (a 1 MHz piezoelectric transducer, 25 mm in diameter). The reflected signal was collected by the same transducer and displayed on the oscilloscope screen. The measured signal is shown in Figure 7.

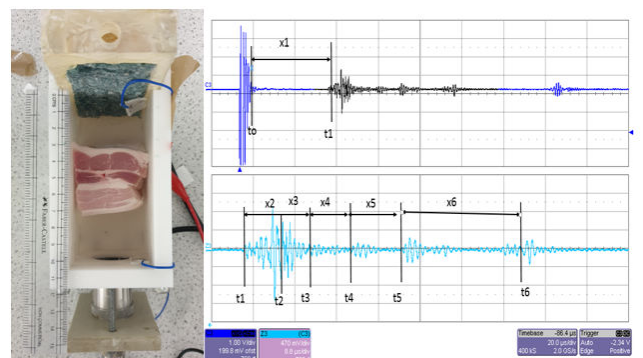


Figure 7. Ultrasound reflection from sample (MF).

Figure 7 shows the reflection signal measured for the sample (MF). All the measurements for both CVP and URD imaging are presented in Table 2. In the URD measurements, the attenuation is double that of the CVP because the measurement in CVP is taken directly from the sample, whereas in URD, the measurement is made by the reflection from the sample. As

can clearly be seen in Figure 7, there is a big difference between the amplitude between the first signal the last signal, while in CVP it is less attenuated.

Table 2. CVP and URD measurement for sample (MF).

x_n	CVP(mm)	URD(mm)
x_1	32.5	28.12
x_2	5.55	5.914
x_3	2.77	3.942
x_4	5.698	5.914
x_5	3.98	9.116
x_6	6.837	18.233
x_7	11.396	-
x_8	5.698	-
x_9	4.55	-
Δx	46.479	43.119

Table 2 shows the signal measurement for 1D imaging in both the CVP and URD methods for the sample (MF). The signals are detected and measured x_7 , x_8 and x_9 in the CVP method, whereas in URD method, these signals are not detected.

Test 3: CVPI: Sample (LMB)

A large piece of pork muscle with the bone (LMB) was place inside the CVP testing rig. The sample was placed 23 mm away from the transducer interface. The ultrasound pulses were sent through the sample via the piezoelectric transducer having 1 MHz frequency and 25 mm in diameter. The CVP signal was generated within the sample and the signal detected by two electrodes placed at the bottom and at the end of the rig. The signal was amplified with an amplification factor of 39 dB and displayed on the oscilloscope. The measured CVP signal is shown in Figure 8.

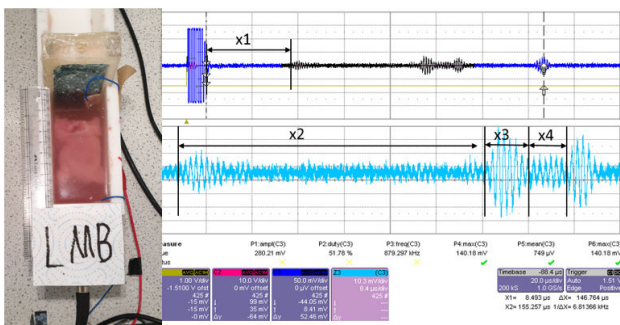


Figure 8. CVP signal measured for the sample (LMB).

The CVP signal measured x_1 at the first boundary of the sample, x_2 is the thickness of the muscle from the first boundary to the first boundary of the bone within the sample, x_3 is the structure between the bone layers, and x_4 is muscle tissue beyond the bone and the end side of the sample. The measured CVPs for each layer are presented in Table 3.

Test 4: URD: Sample (LMB)

The same sample (LMB) was left inside the UVP standard II testing device. The transducer was connected to an ultrasound pulser/receiver with a gain factor of 39 dB. The ultrasound pulses were sent through the water tank via a similar transducer (a 1 MHz piezoelectric transducer). The reflected signal was collected by the same transducer and amplified with an amplification factor of 39 dB. The URD signal was displayed on the oscilloscope screen, and this is presented in Figure 9.

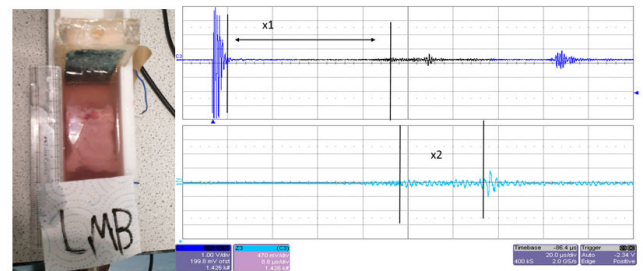


Figure 9. URD signal measured from the sample (LMB).

In Figure 9 we can see the URD imaging system was only able to detect two signal features. According to the measurements, x_1 is the distance between the first boundary of the bone within the sample and the transducer interface and this distance was measured at $x_1=61.8$ mm, this is similar to x_3 in the CVP imaging. The value of x_2 in Figure 9 was measured at 13.04 mm and this is similar to x_5 in the CVP imaging.

Table 3. CVP and URD signal from the sample LMB.

x_n	CVP(mm)	URD(mm)
x_1	23.68	61.8
x_2	6.216	13.04
x_3	33.374	-
x_4	8.306	-
x_5	4.954	-
Δx	52.85	-

In both CVP and URD imaging we can see that the CVP can image three different layers such as x_1 , x_2 and x_4 , whereas the URD was not able to measure any signal within this area of the sample (LMB).

Conclusion

In summary, we have demonstrated the super capability of CVP for tissue imaging in medicine. The CVP signal measured from animal tissue (pork) using our current instrumentations, and demonstrated that, CVP can reveal specific physiochemical structures of colloids or tissue which the conventional ultrasound technique cannot see. The three different samples (M, MF, and LMB) have been tested on CVP imaging and 1D (URD). The discovery of new finding presented specific tissue structures by comparing images of these two modes of tissue information: specified as being ionic

vibration based, ultrasound impedance reflection intensity based, and conductivity distribution-based tissue information. This work shows the feasibility of CVP imaging for the potential of tissue imaging in medicine.

References

1. Kane D, Grassi W, Sturrock R, et al. A brief history of musculoskeletal ultrasound: 'From bats and ships to babies and hips'. *Rheumatology (Oxford)*. 2004;43:931-3.
2. John G Lynn, Raymund L, Zwemer, et al. A new method for the generation and use of focused ultrasound in experimental biology. *J Gen Physiol*. 1942;26:179-93.
3. Bakeer JB. The history of sonographers. *J Ultrasound Med*. 2005;24:1-14.
4. Debye P. A Method for the Determination of the Mass of Electrolytic Ions. *J Chem. Phys*. 1933;1:13-16.
5. Hermans JJ. Charged colloid particles in an ultrasonic field-II. Particles surrounded by a thin double layer. *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science*. 1938;26:674-83.
6. Rutgers AJ, W Rigole. Ultrasound vibration potential In colloidal solutions, in solutions of electrolytes and in pure liquids. *Transaction of the Faraday Society*. 1957;54:139-43.
7. Booth F, JA Enderby. On Electrical Effects due to Sound Waves in Colloidal Suspensions. *Proceedings of the Physical Society, Section A*. 1952;65:321-4.
8. Zana R, E Yeager. Ultrasonic vibration potentials and their use in the determination of ionic partial molal volumes. *J Phys Chem*. 1967;71:521-36.
9. Ohshima H, AS Dukhin. Colloid vibration potential in a suspension of soft particles. *Journal of Colloid and Interface Science*. 1999;212:449-52.
10. Hossein F, M Wang. Modelling and measurement of ultrasound vibration potential distribution in an agar phantom. *Langmuir*. 2019;1:1-18.

*Correspondence to

Fria Hossein
 School of Chemical and Processes Engineering,
 University of Leeds,
 United Kingdom
 E-mail: py12fah@leeds.ac.uk