THE USE OF PIEZOELECTRIC EFFECT TO IMPROVE INSTRUMENT QUALITY AND PATIENT SAFETY IN LAPAROSCOPIC SURGERY

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SUMMARY – The piezoelectric properties of some natural crystals and polymers can also be used in surgery. For this purpose, a prototype of an endoscopic instrument was constructed with piezoelectric material attached to its working end with the aim of recognizing pulsating blood vessels during laparoscopic surgery. To test the properties of the new instrument in laboratory conditions, simulated blood circulation was used with the possibility of changing pressure and frequency. The instrument was tested in the pressure range of 40-180 mm Hg at constant frequency of 72/min and frequency range of 36-130 beats *per* minute at constant pressure of 120 mm Hg. Test results showed that the instrument with certainty recognized a pulsating "blood vessel" in the expected pressure ranges and at different blood pump frequencies. Given the piezoelectric material's very small dimensions and flexible form, it can be installed at the working end of most standard laparoscopic instruments and thus significantly increase certainty in the recognition of arteries during surgery, which would reduce the possibility of their injury or accidental ligation.

Key words: *Piezosurgery – methods; Laparoscopy – methods; Surgical instruments*

Introduction

Piezoelectric effect is the appearance of electric charge when crystalline material is exposed to pressure[1]. It occurs in natural crystals such as quartz (chemical formula SiO_2)[2] and in some polymers such as polyvinylidene fluoride (PVDF)[3,4]. It is known that piezoelectric material possesses ferroelectric properties. The term piezoelectric originated by analogy to ferromagnetic properties. The term "piezo" comes from the Greek word *piezen*, which means "to squeeze". The Curie brothers discovered piezoelectric effect in 1880[5], but there was very little practical application until 1917, when another Frenchman Paul Langevin used thin quartz plates to generate and detect sound waves in water[6]. His work later led to the development of the sonar.

A piezoelectric effect model was presented by Alexander Meissner in 1927[1]. The quartz crystal had the shape of a round nucleus, with one Si (silicon) and two O (oxygen) atoms alternating inside the nucleus. The quartz crystal must be cut exactly along the x, y and z axes. One crystal cell contains three silicon atoms and six oxygen atoms. The oxygen atoms are connected in pairs. Each silicon atom bears four positive charges, while each oxygen atom pair bears four negative charges (two *per* atom). Quartz is electrically neutral in conditions without the effect of force on crystal. When the external force F acts on the crystal along its x-axis, the crystal's hexagonal part is deformed. Compression force moves the atoms in the

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Received September 13, 2013, accepted December 29, 2014

crystal so that positive charge is generated on the side of the silicon atom and negative charge on the side of the oxygen atom pair. It is evident that the crystal develops electric charge along the y-axis. If the crystal is forced along the x-axis, a charge with reverse polarity is generated along the y-axis as the result of different deformations. This simple model shows that crystal can develop electrical charges on its surface with mechanical deformations. To collect electric charge, conductive electrodes must be placed on the crystal on the opposite sides of the crystal plate's cuts. As a result, the piezoelectric sensor becomes a capacitor with dielectric material that is piezoelectric. The dielectric material acts like a generator of electric charge, and the voltage depends on the thickness of the cut crystal plate[1,2,7].

Using piezoelectric effect, the instrument records, in contact between the work surface of the accelerometer and the wall of a pulsating blood vessel (artery), a pulsation signal, which is picked up by a highly sensitive integrated field effect transistor (FET) amplifier, amplified and transmitted to an operational amplifier. The operational amplifier further amplifies and improves the signal by removing noise using built-in filters[8]. For instrument testing purposes, the output signal is graphically displayed on an oscilloscope or paper strip; for routine application in laparoscopic surgery, it is turned into a sound signal, which is audible in the operating room as loud blood vessel pulsations.

The properties described above can be used in laparoscopic surgery, where a structure normally cannot be felt to determine whether it is a pulsating artery[9], while other methods such as laparoscopic ultrasound color doppler, selective intraoperative angiography, computerized intraoperative tomography and intraoperative nuclear magnetic resonance are not suitable for routine use[10,11]. For this reason, a prototype has been constructed of a laparoscopic instrument (Fig. 1) that is inexpensive, simple and can be combined with other instruments, which improves certainty in artery recognition and does not prolong surgery time.

Material and Methods

The instrument's properties and functioning were tested in laboratory conditions using simulated blood circulation with a pulsating "blood vessel". In the simulated blood flow system, an A-V set segment with a length of 70 mm was removed and an artificial artery of the same length and diameter of 4 mm was installed (IMPRA Carboflo™ STRAIGHT 10S04 C), on which the characteristics of the new instrument were tested.

For testing purposes, the operational amplifier was connected to an electrocardiography (ECG) device and the signal was printed out on the paper strip. The operational amplifier operated with the same medium-range signal amplification throughout the experiment.

During testing, the instrument was affixed to a holder to maintain the same contact quality and strength between the working end and the "blood vessel".

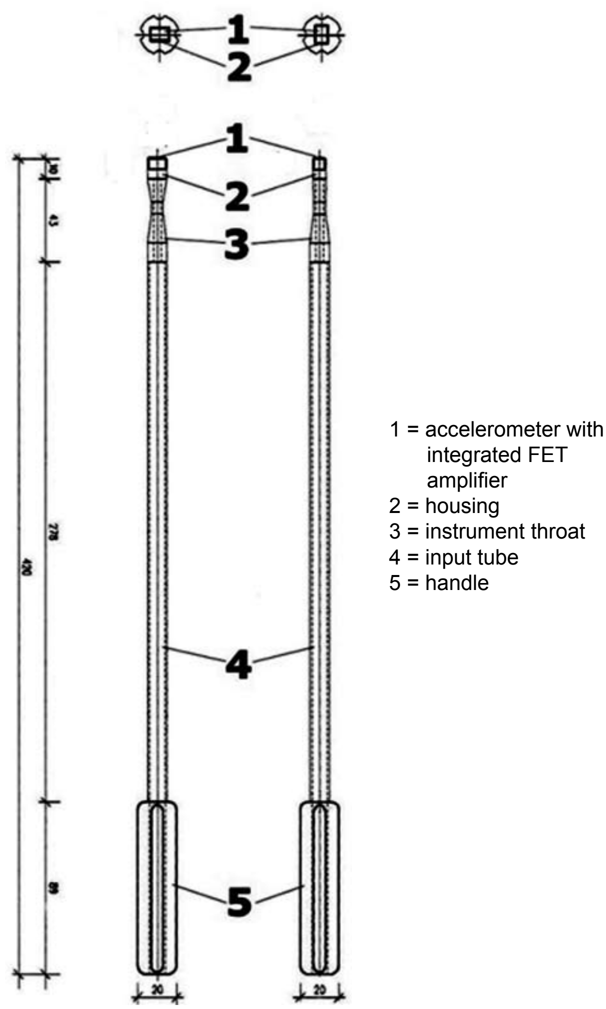


Fig. 1. Instrument drawing (measures in mm).

Table 1. Results of laboratory instrument testing (constant frequency)

Frequency (minute)	Peak-to-peak amplitude (mm)						
	Testing no.						$\overline{SD}$
	1	2	3	4	5	6	
36	12.5	12	12.5	12.5	12.5	12.5	12.4
57	12	12	12	12	12	12	12
72	11	11	10.5	11.5	11	11	11
88	9	9.5	9.5	9.5	9.5	9.5	9.4
110	10	10	10	10	10.5	10.5	10.2
130	10	10	10	9.5	10	10	9.9

In the described laboratory conditions, the following was tested:

1. dependence of the signal recognized by the instrument on the frequency of the working blood pump with constant system pressure;
2. dependence of the signal recognized by the instrument on pressure changes in the system with constant blood pump frequency; and
3. dependence of the signal recognized by the instrument on the examined "blood vessel" on neighboring pulsating blood vessels.

Results

In laboratory conditions, the new instrument proved to be very resistant to mechanical cleaning, rinsing with distilled water, 70% ethanol and glutaraldehyde. The instrument's functioning was not affected by heating in hot water or noise in the work environment. Turning on electricity-consuming devices and their operation in the work environment had no effect on signal amplitude; the same pertained to a TV receiver, radio and mobile phone.

The results of the dependence of signal amplitude recognized by the instrument on a pulsating "blood vessel" on blood pump frequency with constant pressure are shown in Table 1.

The results from Table 1 were entered into a coordinate system and the signal amplitude dependence on frequency was graphically depicted. The amplitude curve showed the instrument to be reliable and stable in recognizing the signal of the pulsating blood vessel in the entire examined frequency range from 36 to 130/min.

The results of the dependence of signal amplitude recognized by the instrument on the pulsating examined blood vessel on changes to circulation pressure with a constant frequency are shown in Table 2.

The results from Table 2 were entered into a coordinate system and the signal amplitude dependence on blood flow pressure was graphically depicted. The amplitude curve showed that signal strength increased with increasing blood flow pressure. The instrument was found to be reliable and recognized the signal of the blood vessel pulsation in the entire range of the examined "systolic" pressures from 40 to 180 mm Hg.

Table 2. Results of laboratory instrument testing (constant pressure)

Pressure (mm Hg)	Peak-to-peak amplitude (mm)						
	Testing no.						$\overline{SD}$
	1	2	3	4	5	6	
40	2.0	2.0	2.0	2.5	2.0	2.0	2.0
60	6.5	6.5	6.5	7.0	6.0	6.0	6.4
80	8.5	8.0	8.0	8.5	8.0	8.5	8.3
100	9.0	9.0	9.0	9.0	9.5	10.0	9.3
120	9.5	9.5	10.0	10.5	10.0	11.0	10.1
150	13.0	13.5	14.5	12.5	13.5	13.0	13.3
180	15.5	15.0	15.0	15.5	15.0	16.0	15.3

Table 3. Results of signal amplitude measurement on examined "blood vessel" with included bypass (constant pressure and frequency)

Pressure / frequency	1	2	3	4	5	6	$\overline{SD}$
120/72	8	7.5	7.5	8,5	8	8	7.9

The results of measuring the signal amplitude of a pulsating blood vessel leaning against another pulsating vessel, with both being part of the same blood flow, showed that there was no difference in signal strength (amplitude) with a bypass and when the bypass was excluded from the blood flow (Table 3).

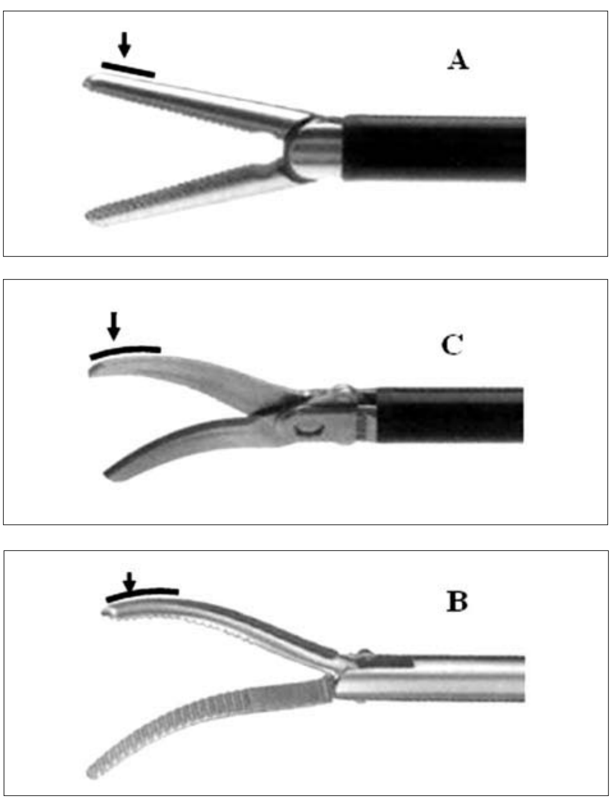
The signal curve showed that a pulsating bypass adversely affected signal clarity, but it did not affect the accuracy of signal recognition. When the examined blood vessel was excluded from blood flow and the bypass touching the vessel was pulsating, the instrument did not recognize pulsing signal on the examined vessel, there was only noise.

Discussion

In routine laparoscopic surgery, one of the leading complications is the injury of blood vessels with resultant bleeding[12-22]. The standard instruments available to surgeons today do not allow for artery recognition apart from visualization[23-27].

Laboratory testing showed in all three parts that the instrument accurately and reliably differentiated signals recognized on the structure it was in contact with, while signal quality did not change with amplification and transmission. The instrument recognized the signal only when the work surface of the accelerometer came in physical contact with the structure on whose surface acceleration changes in the state of matter were taking place.

The instrument's independence of cardiac rhythm frequency and its ability to recognize with appropriate signal amplification pulsations even in the lowest blood flow pressures makes it possible to detect even arteries with very small diameters.



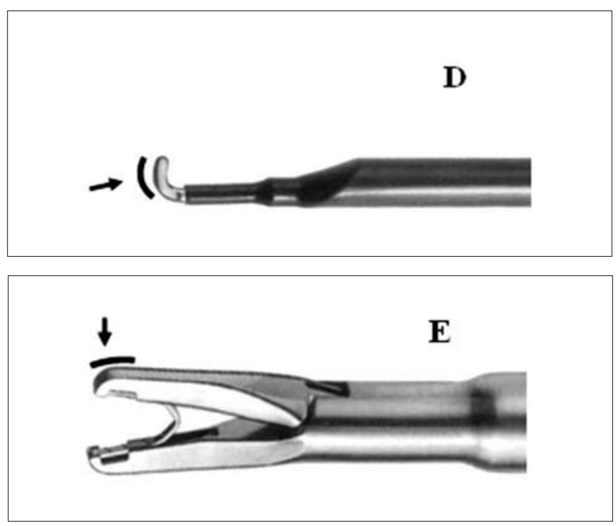


Fig. 2. Possible locations for piezoelectric material on laparoscopic instruments.

A = Dissector
B = Grasping and dissecting forceps
C = Scissors
D = Hook electrode
E = Clip applicator

An accelerometer can be installed at the working end of most laparoscopic instruments (hooks, scissors, forceps, dissectors, etc.) (Fig. 2). Through the use of such instruments, artery detection and recognition, either for ligation preparation or preservation, would be easier and more accurate, which would significantly reduce the possibility of artery injury and increase surgery safety and quality. Such instruments are inexpensive and simple, they increase safety and do not prolong surgery time.

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Sažetak

UPORABA PIEZOELEKTRIČNOG SVOJSTVA U POBOLJŠANJU KVALITETE INSTRUMENATA I SIGURNOSTI BOLESNIKA U LAPAROSKOPSKOJ KIRURGIJI

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Piezoelektrična svojstva nekih prirodnih kristala i nekih polimera moguće je koristiti i u kirurgiji. U tu svrhu konstruiran je prototip endoskopskog instrumenta na čijem je radnom dijelu ugrađen piezoelektrični materijal s ciljem prepoznavanja pulzirajućih krvnih žila tijekom laparoskopskih operacija. Za ispitivanje svojstava novoga instrumenta u laboratorijskim uvjetima korišten je simulirani krvotok s mogućnošću mijenjanja tlaka i frekvencije. Rad instrumenta je ispitivan u rasponu tlakova 40-180 mm Hg uz konstantnu frekvenciju 72/min, te u rasponu frekvencija 36-130 otkucaja u minuti uz konstantan tlak 120 mm Hg. Rezultati ispitivanja pokazuju da instrument sa sigurnošću prepoznaje pulzirajuću „krvnu žilu" u očekivanom rasponu tlakova i pri različitim frekvencijama rada krvne pumpe. S obzirom na to da se radi o vrlo malim dimenzijama i prilagodljivim oblicima piezoelektričkog materijala, moguće ga je postaviti na radni dio većine standardnih laparoskopskih instrumenata i time značajno povećati sigurnost prepoznavanja arterija tijekom operacijskog zahvata, što bi smanjilo mogućnost njihove ozljede ili slučajnog podvezivanja.

Ključne riječi: *Piezokirurgija – metode; Laparoskopija – metode; Kirurški instrumenti*