A STUDY ON HOLE TESTING OF INTRAMEDULLARY NAIL BASED ON ULTRASONIC SENSOR

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Abstract: Intramedullary nail internal fixation is the most prevalent method of treatment of fracture. The study on hole testing and localization of intramedullary nail is one of the most important research topics in present-day orthopedic medicine. This paper gives a new method for hole testing of intramedullary nail based on ultrasonic sensor. Considering the disadvantage, ultrasonic attenuates too fast in bone, it adopts special ultrasonic sensor and appropriate signal testing method to test the hole. It processes the acquired signal and improves conventional image enhancement algorithm. The method can get the clearest image to a great degree in the range of safe dosage of the ultrasonic to achieve testing and localization of the hole. It brings a new method and means to the navigator for intramedullary nail. The method overcomes the disadvantages of X-ray C-arm machine such as radiation damage, low precision and high fabricating cost. The simulation and clinical experiment indicate that the method has high sensitivity and good reproducibility.

KEY WORD Intramedullary Nail, Ultrasonic Sensor, Hole Testing, Image Edge Detection, Image Enhancement

Introduction: The fixation is the key point of three main principles in fracture treatment all the while. The development of fixation principle and method basically reflects the evolvement of fracture treatment. Intramedullary nail internal fixation is one of the important aspects. The latest data indicates: in occident developed country, the application of Intramedullary nail for treatments of long-tube fracture is above 90 percent[1]. X-ray is mostly applied in actual orthopaedics operation for hole testing and localization of intramedullary nail. The application of X-ray in orthopaedics operation is a good method, but some inevitable disadvantages exist in X-ray: (1) radiation damage. The radiation damage of X-ray for body is a sort of small-energy, many-frequency, long time, accumulated damage. If exposed to long time and big dosage X-ray, the apparatus and organization will get damage, sometimes result in cancer and even to death. (2) X-ray has low precision, blurry imaging, low resolving power etc, so high requirement is needed for the doctor. All these are disadvantageous for its popularization and easily result in false judgment. So the research of hole testing and localization of intramedullary nail, which is unharmful for physicians and suffers, is especially important.

Hole Testing of Intramedullary Nail Based on Ultrasonic Sensor:

1. Mechanism of Ultrasonic Imaging

Ultrasonic is a kind of machine vibration transmitted through flexibility medium(solid, liquid, gas). It's frequency is above 20kHz. The range of ultrasonic for imaging is 10^6~5×10^7Hz. when ultrasonic transmits through symmetrical medium it can freely pass along its direction. If it transmits through heterogeneous medium or enters into another medium, reflection and refraction will come into being[2]. The structure of body is a complicated medium whose apparatus and organization has respective and specifically acoustic impedance and decay characteristic. When ultrasonic enters into body, from the surface to the deep, it will pass some apparatus and organization which have different acoustic impedance and decay characteristic to produce different reflection and attenuation. According to strong and feebleness of received ultrasonic, light spots with different brightness display on the screen. Ultrasonic imaging comes into being. According to different imaging mode, ultrasonic imaging can be divided reflected ultrasonic imaging and transmitted ultrasonic imaging.

The ultrasonic sensor is a kind of special sensor which makes use of the peculiarity of ultrasonic to generate and receive ultrasonic. The ultrasonic sensors include two parts: high frequency pulse generators and sensors. The high frequency pulse generators are used to generate

ultrasonic frequency-electricity oscillation and the sensors transform electromagnetism energy into mechanical energy. The piezoelectricity sensors are in common use in medicine which make use of piezoelectricity effect of some crystal[3].

2. Research Content

In order to realize hole testing and localization of intramedullary nail, the system adopts transmitted ultrasonic imaging: One probe for emission and one for receiver. The two probes scan the object in a concentric circle. The ultrasonic signal through body is received, amplified and imaged on the display. Thus the ultrasonic perspective image is acquired (see Figure 1) .

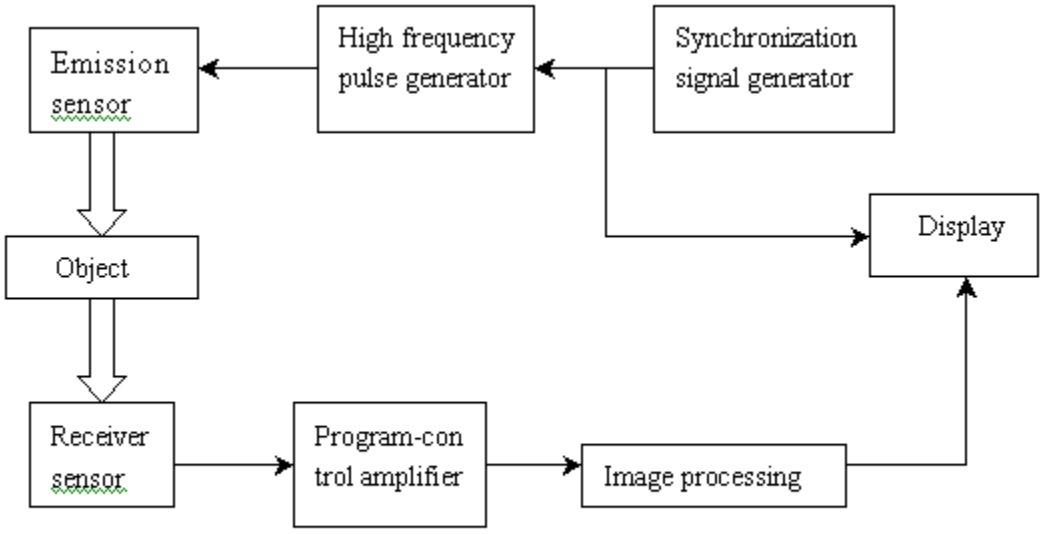

Figure 1. Transmitted Ultrasonic Imaging System

2.1 Ultrasonic attenuation and absorption

Supposed that ultrasonic enters into symmetrical medium along X axis. At lamella dX whose intensity is I_0 the decrement of intensity is $-dI$. According to experiment rule

$$-dI = \alpha I dx \quad (1)$$

here, α is called sound absorption coefficient. Through integral for both sides we can get

$$\int \frac{dI}{I} = -\alpha \int dx \quad (2)$$

that is

$$I = I_0 \exp(-\alpha x) \quad (3)$$

The absorption coefficient of some organization is listed in table 1[4].

Table 1. Some Absorption Coefficient of Body Organization

Organization	Attenuation (dB/cm)	Frequency (MHz)
Muscle	0.96	1.5
Skull	5.10	4.5
Blood	0.95	5.0

2.2 Ultrasonic Transmission at Medium Surface

The transmission energy of ultrasonic in different medium is measured by transmission coefficient. The sound transmission coefficient is expressed by

$$t_p = \frac{P_t}{P_i}$$

□4□

where, P_t is sound pressure value in medium 2, P_i is sound pressure value in medium 1.

According to the condition of continue sound pressure value and continue vertical speed(see Figure 2)

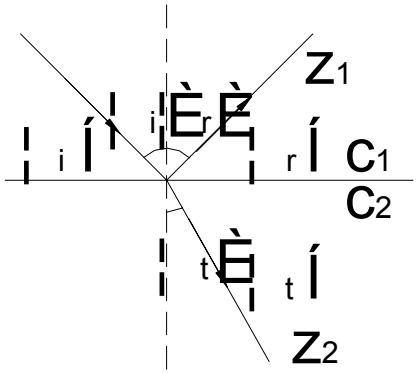

Figure 2. ultrasonic reflection and transmission

$$\frac{P_i}{Z_1}\cos\theta_i - \frac{P_r}{Z_1}\cos\theta_r = \frac{P_t}{Z_2}\cos\theta_t$$

□5□

and $P_r = P_t - P_i$ □so we can get

$$\frac{P_i}{Z_1}\left(\cos\theta_i + \cos\theta_r\right) = P_t\left(\frac{\cos\theta_t}{Z_2} + \frac{\cos\theta_r}{Z_1}\right)$$

□6□

According to law of refection: $\theta_i = \theta_r$

Then

$$t_p = \frac{2Z_2\cos\theta_i}{Z_1\cos\theta_t + Z_2\cos\theta_r}$$

□7□

When the ultrasonic enters into medium along vertical direction

$$t_p = \frac{2Z_2}{Z_2 + Z_1}$$

□8□

2.3 The Selection of Ultrasonic Safe Dosage

Since ultrasonic was introduced in medicine field, the safety of ultrasonic is considered all the time. The figure 3 shows the distribution range of ultrasonic safe dosage. From figure 3 the conclusion can be drawn that the safe dosage of ultrasonic intensity is correlative with irradiation time. The longer irradiation time is, the lower safe ultrasonic intensity is allowed. If the body is exposed to ultrasonic for one second, the safe dosage is 500W/cm^2, however the safe dosage only is 100mW/cm^2 if the body is exposed to ultrasonic for one minute. If the time is longer the safe dosage is lower corresponding. At a certain region, the product of safe dosage intensity and time basically is a constant. So the reasonable safe dosage of diagnostic ultrasonic should include time factor. In this paper considering the disadvantage, ultrasonic attenuates too fast in bone, the bigger ultrasonic dosage is needed. In order to avoid that the ultrasonic produces stationary wave in body and does harm to health, pulse ultrasonic is adopted.

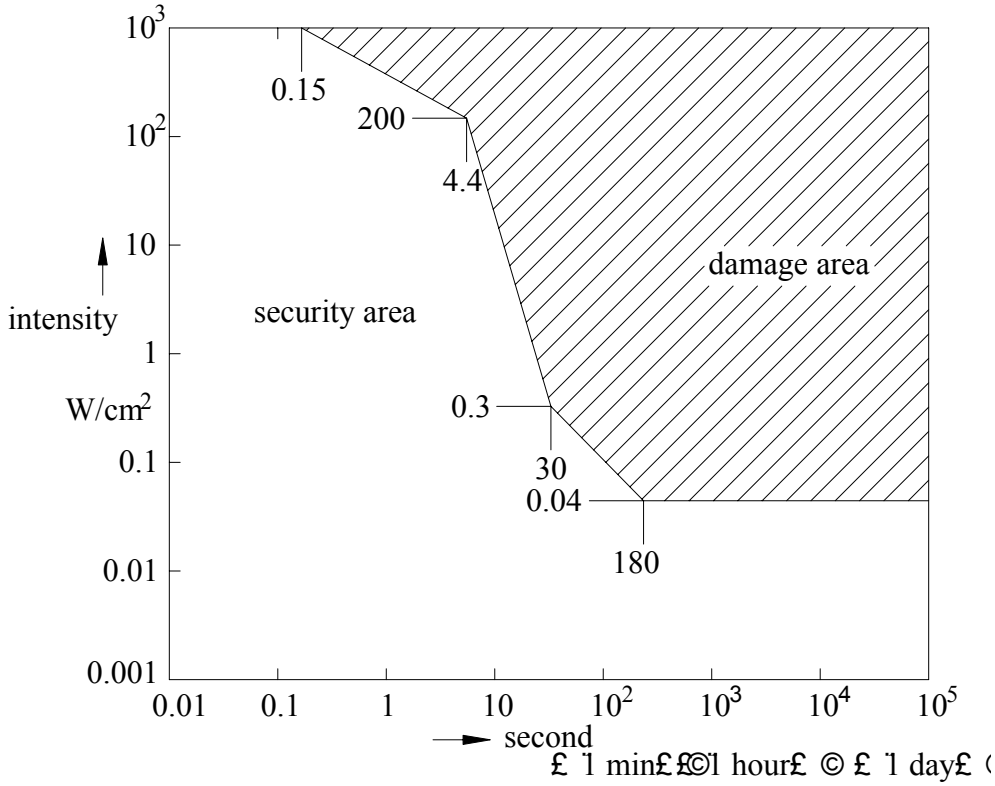

Figure 3. Diagnostic Ultrasonic Range of Safe Dosage

2.4 The Selection of Ultrasonic Sensor

The higher frequency and bigger diameter the ultrasonic sensors have, the better direction and more concentrative the ultrasonic beam have. In order to improve the transmission and direction of ultrasonic beam, the system adopts special high-frequent and big-diameter phalanx sensors. In order to get real time transmission image, the phalanx sensors are adopted which have large amount and small-size phalanx unites.

2.5 The Algorithm of Edge Detection and Image Contrast Enhancement

considering the effect of ultrasonic absorption and attenuation, the direct ultrasonic imaging may not clearly show the hole of intramedullary nail. So some image processing algorithm such

as edge detection and image contrast enhancement is necessary. The paper adopts gray scale image edge detection approach based on pulse coupled neural network. This method eliminates the effect of noise in a certain extent and improves the self-adaptability and veracity of edge detection. Besides, this method improves the quality of edge detection through real time calculating and updating gray value[5]. the paper adopts approach on image contrast enhancement based on wavelet transform. On the basis of taking full advantage of multiscale wavelet analysis, firstly the algorithm takes a step of wavelet shrinkage and then differently enhances the coefficients at each scale. To achieve a better visual effect, the algorithm takes in account human visual system while enhancing the wavelet coefficients [6].Experiment of the algorithm demonstrates that hole imaging is clear. The edge detection and image enhancement make hole imaging clear and enhance contrast of the image with good visual effect .

Discussion: The study on hole testing of intramedullary nail based on ultrasonic sensor is a new method for hole testing in operation of intramedullary nail internal fixation. Considering the strong reflection on the surface between different medium and the ultrasonic attenuation in bone. The ultrasonic intensity should be enough strong to get the image of hole. At the same time, too strong intensity will do harm to health. So selecting an appropriate intensity is an important task. In the design 400W/cm^2 intensity is safe and enough to get the image. On the other hand, the special sensors had been developed to improve the transmission and direction of ultrasonic beam.

Conclusions: The paper gives a new method for hole testing of intramedullary nail based on ultrasonic sensor. The method can get the clearest image to a great degree in the range of safe dosage of the ultrasonic to achieve testing and localization of the hole. It brings a new method and means to the navigator for intramedullary nail. The method overcomes the disadvantages of X-ray such as radiation damage, low precision and high fabricating cost. The simulation and clinical experiment indicate that the method has high sensitivity and good reproducibility.

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