

Fuzzy RASP Determination by 1kHz Ultrasonic Probe for Total Hip Arthroplasty

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Abstract—This paper describes an effective system of selecting most suitable rasp for the patients. We suggest the ultrasonic system with a single ultrasonic probe. Firstly, we make a knock to the upper point of the rasp inserted with a hammer which has the trigger signals. We detected the acoustic signals with the knocking signals. An ultrasonic probe is fixed in the upper side of the rasp with a built-in magnet. A personal computer got the acoustic data. In the surgery, the surgeon tries to adapt for the patient from the small size rasp to the larger size rasp in turn. There is a correlation between the degree of tightening and the attenuation time of acoustic signal for the knocked sound by a hammer when inserting the rasp. The higher tightened degree implies shorter attenuation period. At the present time, the surgeon's experience chooses the suitable rasp. Therefore, we suggest the rasp determination system which selects the suitable rasp by fuzzy inference which dynamically corresponds for each patient. As the result, we successfully determined the suitable rasp in comparison to the results obtained from the practical surgery. We could indicate the indexes in order to judge how degree the rasp fits in the clinical treatment.

Keywords— *fuzzy inference, ultrasonic system, suitable rasp, total hip Arthroplasty (THA)*

I. INTRODUCTION

A joint replacement consists in replacing a damaged joint with a prosthesis. In the orthopedic surgery, the arthritic or dysfunctional joint surface is replaced with an orthopaedic prosthesis [1]. Total hip arthroplasty (THA), which rebuilds the damaged hip joint with some implants, is operated to treat the hip joint diseases such as osteoarthritis, etc. The THA implants mainly consist of cup, liner, head and stem that play a role of acetabulum, hip cartilage, head of femur, and femur, respectively. The principal complication after THA is dislocation [2]. The primal mechanisms of dislocation are impingement of the femoral neck on the cup liner, impingement of the femur on the pelvis, and spontaneous

dislocation due to excessive external force against muscular force. For example a hip joint that is affected by osteoarthritis may be replaced entirely with a prosthetic hip. This would involve replacing both the acetabulum, hip socket, and the head and neck of the femur. The purpose of this procedure is to relieve pain, to restore range of motion and to improve walking ability, thus leading to the improvement of muscle strength.

Joint replacement surgery is becoming a more common practice [3] [4]. The prosthetic implant used in hip replacement consists of different parts, the acetabular cup, the femoral component and the articular interface. The femoral component is the component that fits in the femur. The use of cementless femoral implants for total hip arthroplasty has increased in popularity over the last few decades [5]. Numerous implant designs based on different views concerning implant fixation are currently available. Bone is removed and the femur is shaped to accept the femoral stem with attached prosthetic femoral head or ball. Options exist for different patients and indications. Correct selection of the prosthesis is important [6], [7]. The selection of the optimum size and type of implant to fit the anatomical characteristics of the individual patient is important in order to avoid postoperative complications such as dislocation or loosening [8]-[10]. Regardless of implant design, primary stability of the cementless femoral implants in the femoral canal must be achieved at the time of operation and is really important for osseointegration, long-term fixation and clinical success [11]-[13].

The surgeon's experience in choosing the rasp size to be implanted is fundamental to achieve good fixation. However, especially for complicated cases, there is still the risk that the stem size chosen might be unsuitable. To solve the problem, References [14] and [15] described the mechanical stability at the time of implantation. Moreover, in order to do more quantitative evaluation and analysis, we propose how to select the most suitable stem for the patients by using the ultrasonic system in our study. The fuzzy inference which dynamically

corresponds for each patient is able to solve the problem of the Individual difference. As the results, we were able to select the suitable rasp with higher accuracy.

II. TOTAL HIP ARTHROPLASTY

Hip fractures occur as a result of major or minor trauma. In elderly patients with bones weakened by osteoporosis, relatively little trauma, even walking, may result in a hip fracture. The hip is made of a ball and a socket joint, linking the dome at the head of the femur and the cup in the pelvic bone. A total hip prosthesis is surgically implanted to replace the damaged bone within the hip joint.

Then a metal ball and a metal stem are inserted in the femur and a plastic socket is placed in the enlarged pelvis cup as shown in Fig. 1. The artificial components are fixed in place. The muscles and tendons are then replaced against the bones and the incision is closed.



Figure 1. Total Hip Arthroplasty

Each patient has each various bone in the hip. So the surgeon has to find the most suitable rasp for the patient while operating. In the present situation, there are some differences of selecting the suitable rasp. Therefore, we propose the determination system of selecting the suitable rasp for the patient.

III. MEASUREMENT SYSTEM

We show our system in Fig. 2. The center frequency of the single ultrasonic probe is 1,000Hz. The acquired ultrasonic waveform is analyzed by a personal computer.

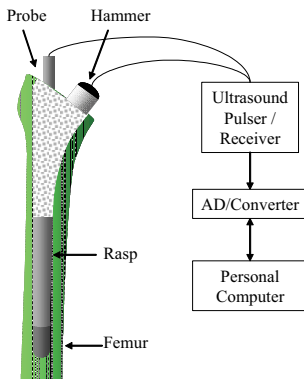


Figure 2. Measurement System

At first, we make a knock to the upper point of the rasp inserted with a hammer which has the trigger signals. By using the knocking signals, we measured the acoustic signals. The microphone for measuring (10mmΦ) is fixed in the upper side of the rasp with a built-in magnet. The acoustic data is changed to the digital data by the AD converter (Picoscope ADC-212/100), and is sent to the personal computer.

A. Experimental Materials

In the clinical treatment, one of the indexes to judge how degree the rasp fits for the patient is the knocked sound by a hammer when inserting the rasp. The surgeon recognizes that the dull knocked sound means the loose fixed. From the physical opinion, in the case of loose fixing, the attenuation time of amplitude is long because the acoustic energy continues to transmit into the rasp. On the other side, in the case of tight fixing, the attenuation time of amplitude is short because the acoustic energy transmits from the rasp to the external fixed object and is absorbed on the early stage.

At first, we do envelope processing to the positive area of the acoustic wave as shown in Fig. 3. In this figure, we define the maximum of the attenuation value as $A_{\max}$ and the time at that time as $T_{\max}$. A_{10} is $A_{\max} / 10$. After the time of $T_{\max}$, we define the time as T_{10} when the value is less than A_{10} . The attenuation time is obtained by (1). We estimate the degree of fixing by using this derived attenuation time.

$$T_{\text{ATT}} = T_{10} - T_{\max} \quad (1)$$

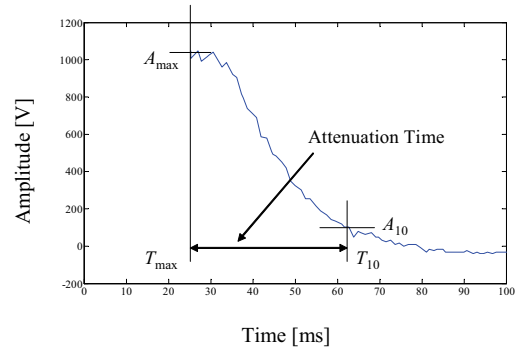


Figure 3. Measurement System

B. Fuzzy Inference

We propose a fuzzy evaluation system with two features, the attenuation time and the difference time. The difference time defines as the time between the attenuation time of the rasp and that of the one size smaller rasp. From the obtained coefficients, Knowledge 1, 2, 3 and 4 are derived.

- Knowledge 1: The tight fixing has the short attenuation time.
- Knowledge 2: The tight fixing has the short difference time.
- Knowledge 3: The attenuation time depends on the fixed degree.
- Knowledge 4: The difference time depends on the fixed degree.

These are converted to the following fuzzy if-then rules.

- Rule 1: IF *Attenuation time* is *Short* THEN the degree of fixing is High.
- Rule 2: IF *Difference time* is *Short* THEN the degree of fixing is High.

The fuzzy if-then rules are represented by the fuzzy membership functions as shown in Fig. 4.

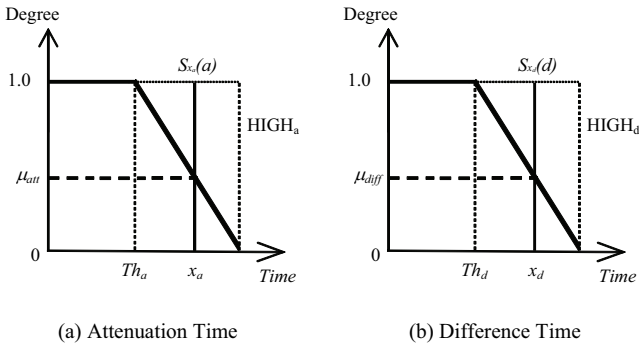


Figure 4. Fuzzy membership function

In this figure, the notations, Th_a and Th_d denote thresholds of *Attenuation Time* and *Difference Time*, respectively. The notation Th_a is determined as the time which is the standard deviation being shorter than the mean of the attenuation time. The notation Th_d is determined as the time which is the standard deviation being shorter than the mean of the difference time. Two fuzzy degrees, μ_{att} and μ_{diff} are calculated by (3) and (4).

$$\mu_{att}(x, y) = \min(S_{x_a}(a), HIGH_a) \quad (3)$$

$$\mu_{diff}(x, y) = \min(S_{x_d}(d), HIGH_d) \quad (4)$$

The fuzzy singleton functions $S_{x_a}(a)$ and $S_{x_d}(d)$ are defined by (5) and (6).

$$S_{x_a}(a) = \begin{cases} 1 & \text{if } a = x_a \\ 0 & \text{otherwise} \end{cases} \quad (5)$$

$$S_{x_d}(d) = \begin{cases} 1 & \text{if } d = x_d \\ 0 & \text{otherwise} \end{cases} \quad (6)$$

TABLE I. THRESHOLD OF FUZZY MEMBERSHIP FUNCTION (SUBJECT1)

	Attenuation Time MF Th _a	Difference Time MF Th _d
Rasp 4	30.61	-
Rasp 5	23.22	2.21
Rasp 6	18.91	4.73
Rasp 7	18.91	-1.73
Rasp 8	14.75	-0.41
Rasp 9	18.51	-2.57
Rasp 10	-	-

TABLE II. THRESHOLD OF FUZZY MEMBERSHIP FUNCTION (SUBJECT2)

	Attenuation Time MF Th _a	Difference Time MF Th _d
Rasp 4	-	-
Rasp 5	-	-
Rasp 6	-	-
Rasp 7	20.13	-
Rasp 8	17.42	-0.08
Rasp 9	20.79	-2.45
Rasp 10	-	-

TABLE III. THRESHOLD OF FUZZY MEMBERSHIP FUNCTION (SUBJECT3)

	Attenuation Time MF Th _a	Difference Time MF Th _d
Rasp 4	-	-
Rasp 5	23.19	-
Rasp 6	18.53	2.95
Rasp 7	19.41	-2.09
Rasp 8	17.30	-0.13
Rasp 9	-	-
Rasp 10	-	-

TABLE IV. THRESHOLD OF FUZZY MEMBERSHIP FUNCTION (SUBJECT4)

	Attenuation Time MF Th _a	Difference Time MF Th _d
Rasp 4	-	-
Rasp 5	-	-
Rasp 6	18.60	-
Rasp 7	20.52	-0.38
Rasp 8	15.74	0.73
Rasp 9	-	-
Rasp 10	-	-

TABLE V. THRESHOLD OF FUZZY MEMBERSHIP FUNCTION (SUBJECT5)

	Attenuation Time MF Th _a	Difference Time MF Th _d
Rasp 4	28.44	-
Rasp 5	25.48	2.17
Rasp 6	21.88	2.93
Rasp 7	-	-
Rasp 8	-	-
Rasp 9	-	-
Rasp 10	-	-

TABLE VI. THRESHOLD OF FUZZY MEMBERSHIP FUNCTION (SUBJECT6)

	Attenuation Time MF Th _a	Difference Time MF Th _d
Rasp 4	27.50	-
Rasp 5	24.58	2.15
Rasp 6	20.51	3.00
Rasp 7	20.64	-0.27
Rasp 8	16.39	0.19
Rasp 9	19.72	5.28
Rasp 10	-	-

TABLE VII. THRESHOLD OF FUZZY MEMBERSHIP FUNCTION (SUBJECT7)

	Attenuation Time MF Th _a	Difference Time MF Th _d
Rasp 4	30.94	-
Rasp 5	28.42	2.01
Rasp 6	22.59	3.80
Rasp 7	23.04	-0.62
Rasp 8	16.65	2.69
Rasp 9	-	-
Rasp 10	-	-

TABLE VIII. THRESHOLD OF FUZZY MEMBERSHIP FUNCTION (SUBJECT8)

	Attenuation Time MF Th _a	Difference Time MF Th _d
Rasp 4	27.50	-
Rasp 5	23.19	6.04
Rasp 6	19.13	2.95
Rasp 7	19.82	-1.27
Rasp 8	-	-
Rasp 9	-	-
Rasp 10	-	-

After consideration of the thresholds on these tables above, the threshold of the attenuation time MF Th_a is more adaptable than that of the difference time MF Th_d. Therefore, we calculate the adaptable ratio ($=0.823$) and put the adaptable ratio to the fuzzy membership functions. The total degree μ_{fix} is calculated by (7).

$$\mu_{fix} = \mu_{att}(x) * ratio + \mu_{diff}(x) * (1 - ratio) \quad (7)$$

IV. EXPERIMENTAL RESULTS

We applied our proposed system to 8 total hip arthroplasty patients. The result of the fixed rasp size and the analyzed rasp size was shown in TABLE IX. The attenuation time measured in the practical surgery is showed in Fig. 5. In this figure, the horizontal-axis means the size of the rasp and the vertical-axis means the attenuation time.

By using our proposed method, we were able to select the suitable rasp of 7 patients. As concerns Subjects 1 and 7, there are two sizes of the determined rasp. Because these subjects

have the fixed rasp which is one size larger than the rasp with the shortest attenuation time, it is left out of consideration that the determined rasp has two types which are the fixed size rasp and the one size smaller rasp. As concerns Subjects 2 and 5, we were not able to select the suitable rasp because the difference time is relatively large as shown in Fig. 5. As the result, the effectiveness of selecting the suitable rasp is 87.5%.

TABLE IX. RESULT OF RASP SIZE

	Fixed Size	Determined Size
Subject 1	10	9 or 10
Subject 2	9	-
Subject 3	8	8
Subject 4	8	8
Subject 5	6	5 or 6
Subject 6	9	9
Subject 7	8	7 or 8
Subject 8	7	7

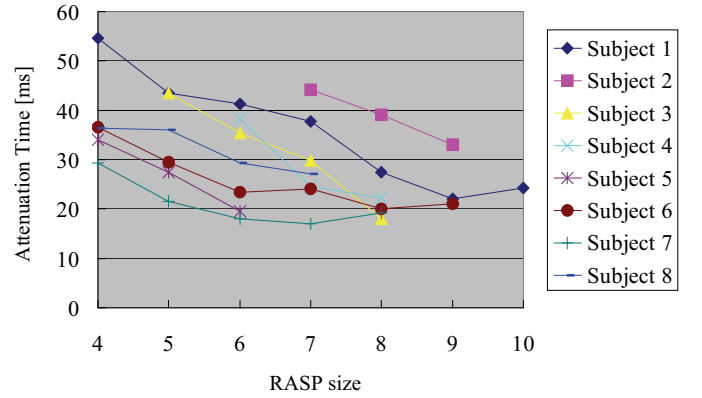


Figure 5. Rasp data in the practical surgery

V. CONCLUSIONS

In this paper, we have proposed a rasp determination system for total hip arthroplasty patients. The acquired ultrasonic waveform with the single ultrasonic probe with the center frequency 1,000Hz is analyzed by a personal computer. At first, we make a knock to the upper point of the rasp inserted with a hammer which has the trigger signals. By using the knocking signals, we measured the acoustic signals. The ultrasonic probe for measuring is fixed in the upper side of the rasp with a built-in magnet. The acoustic data is changed to the digital data by the AD converter and is sent to the personal computer. In the surgery, the surgeon tries to adapt for the patient from the small size rasp to the larger size rasp in turn. Therefore, our system which selects the best suitable rasp by using the attenuation time is superior for surgeons and patients of total hip arthroplasty.

As the result, we successfully determined the suitable rasp in comparison to the results obtained from the practical surgery.

It is thought the indexes in order to judge how degree the rasp fits in the clinical treatment.

It remains as future works to consider the much better effective method and to apply the method to total hip arthroplasty patients.

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