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Development of roll-over support system with EMG control for cancer bone metastasis patients

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Abstract—**Currently, over seven million people die of cancer each year; some of whom suffer from pain caused by bone metastasis. In their final stages of life, the pain is such that they cannot even roll over, one of the activities of daily life. With this in mind, in this research, we aim to develop equipment for patients with cancer bone metastasis to support roll-overs in terminal care. Specifically, the EMG signal, which is the input signal of the equipment, is discussed in this paper. The activities of four muscles affecting trunk movement were monitored during the process of rolling over. Following an EMG experiment with four subjects, the internal abdominal oblique (IO) muscle was seen to be active in the early stages of roll-over motion, although IO muscle was relatively prevalent in previous works. If we support roll-over at this point, the patient feels no pain, because the timing is detected before the strongest burden movement, which involves buoying the trunk and rotating the pelvis. Hence, the EMG signal of the IO muscle is suitable for the input of the signal to support roll-overs.**

I. Introduction

Death is inevitable for each human being, ever since his or her birth, no matter how medical technology develops and how society increases in affluence. Cancer is the biggest global killer, accounting for 7.6 million people per year (13% of all deaths) [1]. They die in pain of cancer, which spreads to the bone in its final stage [2]. As the cancer spreads to the bone, the spinal column becomes increasingly fragile and breaks and the pressure on the spine causes pain [3]. Furthermore, if elderly, they may become bedridden and develop dementia because of the decrease of physical and mental activities.

Medical treatments for cancer bone metastasis shouldn't be categorically selected, because the choice of treatment involves consideration of many complex factors. It is important to respect the wishes of the patient and those of his or her family concerning how they spend their remaining days [4]. However, considering the limited life expectancy, non-operative treatments, such as radiation therapy, are often selected, because operative treatment involves a high risk of decline in the quality of life (QOL) [4][5]. In particular, when the life expectation is a few months, a spinal brace (a hard or canvas corset) is most useful for reducing the risk of spinal fractures and pain caused by pressure on the spine [5][6].

Although a spinal brace has these merits, there are also some problems. Namely, the lumbar movement worsens and the trunk, abdominal and back muscles all weaken. On the other hand, if patients fail to use the spinal brace, some cannot even roll-over because of severe pain, and others break their spine by turning over. In more severe cases, some patients hardly move, in fear of pain and fractures.

Under these circumstances, roll–over, which is one of the activities of daily life (ADL), is highly significant from the perspective of not only preventing bedsores and a decline in physical function but also a change of pace and increasing patients' desire to realize their will.

Accordingly, from improvement of QOL and acquirement of ADL, equipment must be developed to support roll over appropriately only when a patient is willing to roll over.

However, there are few papers covering rolling over, despite the importance of research in this area.

In 1989, Richter et al. began studies on rolling over by analyzing it qualitatively [7]. Around the same time, Hoshimiya et al. reported an electromyogram (EMG) during rolling over as a basic study of functional electrical stimulation [8]-[10]. There are also some reports concerning differences in EMG between healthy subjects and paralyzed patients [11] or elderly and younger subjects respectively [12]. These days, Nozaki et al. have researched the pattern classification of rolling over and an estimation of roll-over ability [13]. These studies are important as fundamental research to comprehend the entire concept of rolling over. For example, these researches reveal that external abdominal oblique muscles and erector spine muscles are active in the roll-over process. Nevertheless, these remain inadequate to use the equipment for supporting roll-overs, because most studies used wire electrodes or analyzed EMG signals of one roll-over type.

We conducted experiments of motion and EMG measurement with four subjects. In this paper, we report on surface EMG signals at an early stage of roll-over, which would be an input signal of a system to support rolling over.

This paper is constructed with chapter 1 as the background to cancer bone metastasis and rolling over, chapter 2 defining the concept of research and equipment, chapter 3 covering the

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motion analysis of roll-over, chapter 4 covering EMG analysis, chapter 5 covering the input signal of the equipment and chapter 6 featuring the conclusion and future work.

II. Concept

The concept is a technological application, intended to improve QOL before death rather than prolong life. To realize this, we need to establish a balance between rest and acting under an environment where the patient feels comfortable. In concrete terms, we develop equipment which detects the intent of the patient to roll over and supports the roll-over with the required power to prevent twisting the trunk, spine compression and fracture.

Therefore, this equipment is composed of two elements; one of which precisely and swiftly detects the patient's intent as an input, the other of which supports the roll-over with the required power as an output. In this report, we describe the former input signal.

There are several means to read roll-over signals, such as electroencephalograms [14][14], EMG [16][17], and pressure sensors [12]. We selected the surface EMG as the input, because of the following three attributes, namely a noninvasive technique, understanding the activity of each muscle, and reading the intention earlier than the movement.

III. Motion Measurement Experiment

A. Definition

We define roll-over as a continuum movement involving a deliberate change of posture, from a supine position to a lateral or prone position.

In addition, a roll-over is categorized as an upper limb precedent type (ULPT), lower limb precedent type (LLPT) or lower limb flexion type (LLFT) by focusing attention on the difference in the motion at the first stage of roll-over, although as Richter et al. report, the whole roll-over process could be specifically classified into nineteen types [7]. First, the ULPT has the characteristic that the start of upper limb motion comes before that of pelvis rotation. Next, the LLPT is defined as the roll over that the start of pelvis rotation comes before that of upper limb motion without using reaction force of lower limb. Finally, the LLFT is the roll-over using reaction force of lower limb with the knee bent.

B. Purpose

The roll-over motion measurement was conducted by using a motion capture system to analyze the shoulder and pelvis movements. Moreover, the differences between the three types of roll-over were also checked.

C. Experimental equipment

Vicon612 and nine cameras were used as a 3D motion capture system. The measurement accuracy was to within less than 1 (mm), and the sampling frequency was 100 (Hz).

D. Method

Four markers were placed on the right and left acrominon and anterior superior iliac spine of one healthy subject who was 23 years old (Fig. 1). Roll-overs movements were performed twenty times with many patterns.

E. Results and Discussion

All movements could be categorized as ULPT, LLPT or LLFT. Furthermore, we defined the two lines formed by the right and left markers of the shoulder and pelvis in supine position as the initial lines respectively, and calculated the angles *θs, θp*, where *θs, θp* were the angles between each initial line and shoulder and pelvis lines during the roll-over (Fig. 2). As shown in Fig. 3, in ULPT, the shoulder angle always preceded the pelvis angle at all times. In the case of LLPT, the pelvis angle initially preceded the shoulder angle. However, the shoulder angle caught up with the pelvis rotation at about 90 (deg) and then preceded it using the inertia of left thorax. In LLFT, the pelvis rotation initially started with the reaction force before the left shoulder was buoyed. However, the shoulder angle caught up with the pelvis rotation at about 90 (deg) as is the case with LLPT. After that, the shoulder line was on the parallel with the pelvis line until the roll-over was finished.

IV. EMG Experiment

A. Purpose

The purpose of this EMG experiment is to find muscles and its proper electrode positions where surface EMG signals are generated at an early stage of rolling over, and to apply them to the input signals of equipment which supports rolling over.

B. Experimental Subject

Four subjects were studied, regardless of age and sex. Their properties were shown in TABLE I. They received detailed

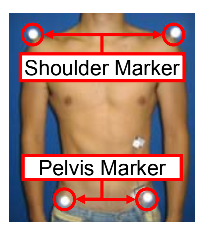

Fig. 1. Marker Position

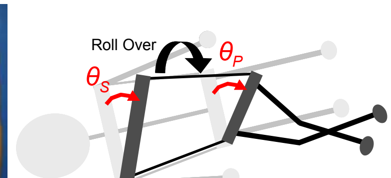

Fig. 2. Definition of the angles.

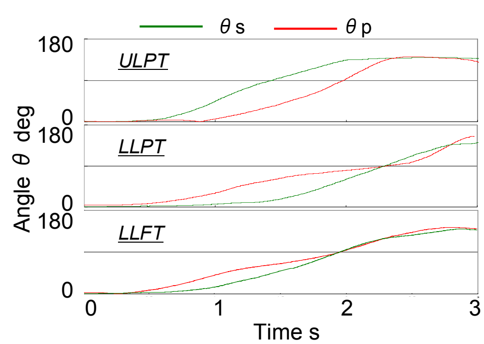

Fig. 3. Difference in the angles between roll-over types.

TABLE I
SUBJECTS' PROPERTIES

No.	Age	Sex	Height cm	Weight kg
1	23	Male	168	60
2	24	Male	170	60
3	62	Male	163	65
4	92	Female	143	39

accounts of the experimental objective and practiced hard to get used to the movements in advance.

C. Equipment

The EMG signals were obtained by surface electrodes (Biometrics Ltd.) and DataLog (Biometrics Ltd.). The EMG signals were sampled at a rate of 1000 (Hz).

D. Electrode positions

Electrodes were placed on the external abdominal oblique (EO) and the internal abdominal oblique (IO) muscle in four positions, and the rectus abdominis (RA) and the erector spinae (EP) muscle in six positions. Electrode positions and directions of muscle fiber are shown in Fig. 4.

However, the electrodes of the EO and IO muscles were the same positions. Therefore, we had to confirm that the detected EMG signals were generated in the target muscle. The EMG signal was transformed by Fast Fourier Transform (FFT) into power density spectrum to use the feature that the high frequency component of the surface EMG is attenuated, depending on the distance from the muscle to the electrode [18]. ZeroCrossing (ZC) and Mean Power Frequency (MPF) were used as the evaluation index, because these two parameters had been confirmed the effectiveness as the indexes to recognize the differences in EMG between surface and deep layer muscles in previous experiment [19].

Firstly, ZC is the number of times that the waveform crosses zero and is defined as follows: Given two consecutive EMG samples x_k and x_{k+1}, ZC is incremented if:

$$\mathrm{sgn}(-x_k \times x_{k+1}) = 1 \tag{1}$$

with $\mathrm{sgn}(x) = 1$, if $x > 0$, 0 otherwise. This parameter provides a rough estimation of the properties in the frequency domain. In other words, ZC tends to be large when the high frequency component is large and small when it is small respectively.

Next, MPF expresses the center of the spectrum distribution. For example, MPF becomes small if whole spectrum moves to low frequency range. The MPF equation is written as:

$$MPF = \sum \left(f(i) \times Z(i)\right) \Big/ \sum Z(i) \tag{2}$$

where f (i) is the ith frequency and Z (i) is the spectral power in the ith frequency.

At the electrode positions which were selected in this experiment, the layer of IO muscle is deeper than that of EO muscle. For this reason, it had been predicted that the high frequency component of IO muscle's EMG was smaller than that of EO muscles. We confirmed that ZC and MPF of EO muscle were larger than those of IO muscle. Hence, this showed that electrode positions and direction were adequate.

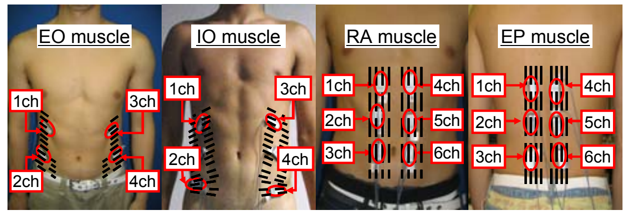

Fig. 4. Electrode positions.

E. Motion

Each subject performed roll-over motions of ULPT, LLPT and LLFT seven times respectively. However, all subjects were requested to roll toward and over their left side. Additionally, subjects had the event marker with their hand and pushed its switch during roll-over so that the roll-over section in EMG signal was recognized and the EMG data was synchronized with the data of 3D motion capture system.

F. Data Processing

The surface EMG was taken as an absolute value and passed the second-order low-pass filter with a cutoff frequency of 20 (Hz).

G. Result and discussion

Taking account of the muscles' position and muscle fibers' direction, which are shown in Fig. 4, the EMG results are associated with the sequences of roll-over movement.

The EMG results of only one subject (No. 2 in Table1) are shown in this paper, because the tendency of EMG signals which were generated in the same roll-over type was similar regardless of the subjects. However, the myoelectric potential of aged subject (No.4 in Table 1) was small.

1) ULPT

In an early stage ($0 < \theta s < 30$ (deg)), the right part of IO muscle (1,2ch in Fig. 6) was very active, and the upper left part of EO muscle (3ch in fig. 5) was rather active. These were muscle activities to buoy the left shoulder and start twisting the trunk. At the same time, the lower part of EP muscle (3,6ch in Fig. 8) was contracted to support the buoyed trunk.

The EMG signals generated from the lower left IO muscle (3ch in Fig. 6) and the right EO muscle (1,2ch in Fig. 5) were confirmed at a midway stage ($30 \leq \theta s \leq 90$(deg)). The pelvis was rotated with the right side body as an axis, and the left lower limb was buoyed by the cooperative contraction of this two muscles. As in the case of the early stage, the left EP muscle (4,5,6ch in Fig. 8) was active to support the buoyed left trunk.

At a last stage ($\theta s > 90$(deg)), strong muscle activity was not confirmed at any muscles, because the position became smoothly prone, that is, the rotations were smoothly finished from shoulder to waist, pelvis and lower limb using the gravitational and inertial forces.

The heartbeat was detected at RA muscle as Fig. 7 through the entire process. Furthermore, the heartbeat had a strong effect on the EMG of EP muscle.

2) LLPT

In an early stage ($0 < \theta p < 30$(deg)), the lower left IO muscle (4ch in Fig. 10) and the upper right EO muscle (1ch in Fig. 9) were strongly contracted. The pelvis could start being rotated by these muscles' activities. At the same time, the lower left EP muscle (3,4,5,6ch in Fig.12) became rather active to support the trunk which the pelvis rotation made buoyed.

On the other hand, at a midway stage ($30 \leq \theta p \leq 90$ (deg)) when the waist was more twisted, the active section of the EP muscle extended over the whole left part to stay the left trunk and pelvis which were floated in the midair. Even as the EP muscle's activity, the EMG of the left IO muscle (3,4ch in Fig. 10) peaked to rotate the pelvis. Moreover, the right IO muscle (1,2ch in Fig. 10) and the lower left EO muscle (4ch in Fig. 9) were strongly contracted to start buoying the left shoulder.

In a last stage (θs, $\theta p > 90$(deg)), the activities of many muscles were confirmed (1,2,3ch in Fig. 9, 1,2ch in Fig. 10, 2,3,5,6ch in Fig. 11, and 1ch in Fig.12) to slow down the rotational velocity of the trunk. This resulted in lessening the impact force exerted on the left trunk when the shoulder, waist and pelvis landed at almost the same time.

Through the entire process, the heartbeat had a strong effect on the EMG of EP and RA muscles as in the case with ULPT.

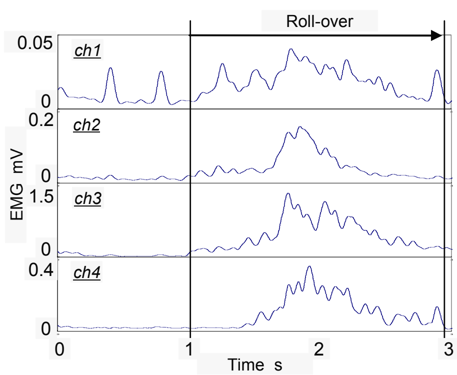

Fig. 5. EMG of EO muscle in ULPT.

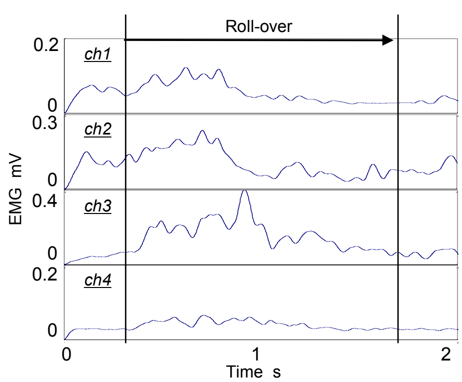

Fig. 6. EMG of IEO muscle in ULPT.

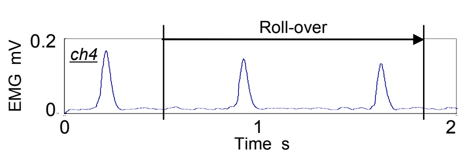

Fig. 7. EMG of RA muscle in UPLT.

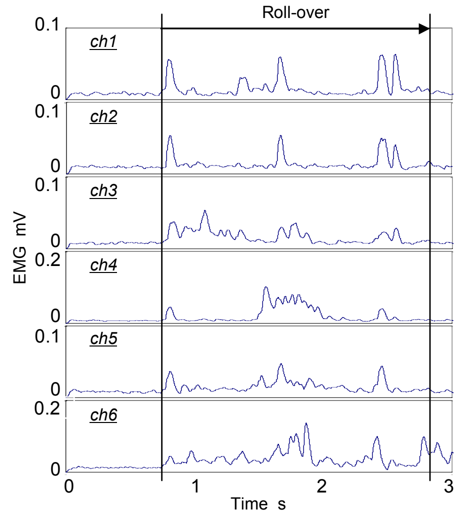

Fig. 8. EMG of EP muscle in ULPT.

3) LLFT

At the stage of knee flexion, the muscle of left femoral region was mainly used to flex the ankle, knee and hip joint. Therefore, the strong activity of the trunk muscles was not confirmed. However, the EO and IO muscles played a supplementary role, because the activities of the lower left EO muscle (4ch in Fig. 12) and the lower IO muscle (2,4ch in Fig. 14) were a little.

In an early stage ($0 < \theta p < 30$(deg)), the left part of IO muscle (3,4ch in Fig. 14) was active. However, the myoelectric potential was one sixth of that in LLPT, whose temporal change in the pelvis rotational angle, θp, was similar. Furthermore, the EMG signal of right EO muscle (1,2ch in Fig. 12) was hardly detected in spite of strong activity in LLPT. This resulted from the differences in how to start rotating the pelvis. Namely, in LLPT, the contraction of the lower left IO muscle and the upper right EO muscle were used. On the other hand, in LLFT, the activity of the trunk muscle was not important, because the pelvis could be efficiently rotated by using the reaction force from planta pedis. This is justified by the related study to show that adductor muscle and gluteus maximus are strongly active when the roll-over motion is conducted with making the knee flexed [8]. At an early stage, the EMG signals of not only EO muscle but also EP muscle (1-6ch in Fig. 15) were detected to support the left trunk, which was buoyed by precedent lower limb, in cooperation with adductor muscle and gluteus maximus.

At an midway stage ($30 \leq \theta p \leq 90$(deg)), the lower left IO muscle continued to be active and the right EO muscle (1,2ch in Fig. 12) started the contraction to carrying on the pelvis rotation. As the trunk was twisted, the rotation of the left thorax and shoulder started following the pelvis rotation.
This motion was confirmed by the EMG of the right IO muscle (1,2ch in Fig. 14) and the left EO muscle (3,4ch in Fig. 12) to buoy the left shoulder.

In the last stage (θs, $\theta p > 90$(deg)), the activities of many muscles were confirmed (1,2,3ch in Fig. 12, 2,3ch in Fig. 14, and 1ch in Fig.15) because of the same reason in LLPT.

Through the entire process, the heartbeat had a strong effect on the EMG of EP and RA muscles as in the case with ULPT.

V. INPUT SIGNAL

Considering the time taken to support, the input signal should preferably be detected at a preliminary or early stage of motion. Therefore, as a result of chapter 4, we selected the EMG signal of the upper IO muscle as the input in ULPT, that of the lower IO muscle in LLPT and LLFT. The EO and EP muscles' signals were confirmed at the early stage. However, the EMG signal of the EO muscle was smaller and slower than that of the IO muscle. Moreover, from the perspective of preventing the bedsore, the choice of EP muscle is rejected.

In this chapter, the relation between these input signals and movement at an early stage is confirmed. Fig. 16 shows the relation between the angles of shoulder and pelvis, the IO muscle's EMG. It was made by using the results of chapters3 and 4. At first, in ULPT, the EMG of the upper IO muscle built towards a peak when the shoulder angle was about 60 (deg) and the pelvis did not yet rotate. If the roll-over is detected at this point, there is enough time to support the process. This is because the point is before when the spine is exposed to maximum stress, that is, when the trunk is buoyed and the pelvis rotated.

Next, the relationship in the LLPT roll-over was confirmed. The EMG of the lower part of the IO part built towards a peak when the pelvis angle was about 30 (deg) and the shoulder did not yet rotate. As is the case with ULPT, this timing is enough to support roll-over, because it is before the spine is exposed to most stress when the trunk is buoyed and the pelvis rotated.

Finally, the relation in the LLFT was discussed. Timing to support the roll over does not matter, because the IO muscle became active toward starting the pelvis rotation.

Hence, the EMG signal of the IO muscle is defined as the input signal of all roll-over type.

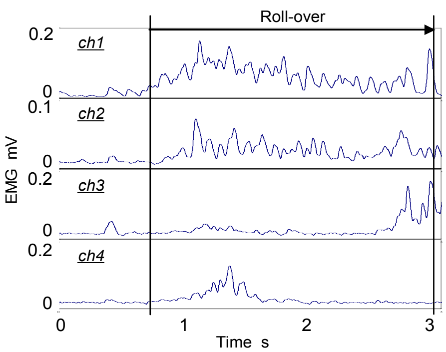

Fig. 9. EMG of EO muscle in LLPT.

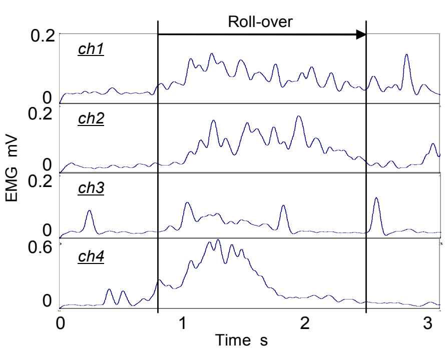

Fig. 10. EMG of IO muscle in LLPT

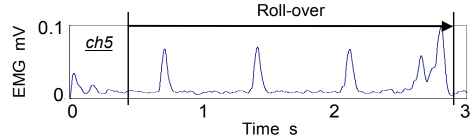

Fig. 11. EMG of RA muscle in LLPT.

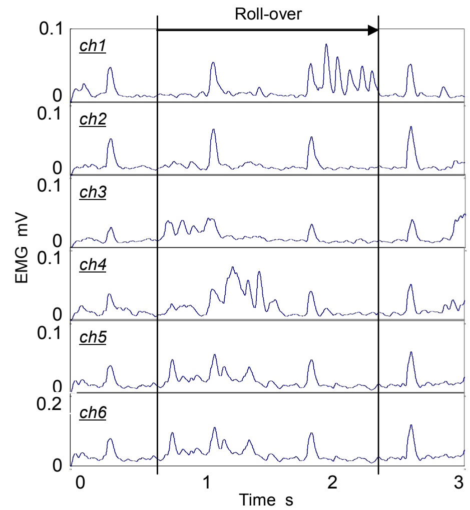

Fig. 11. EMG of EP muscle in LLPT.

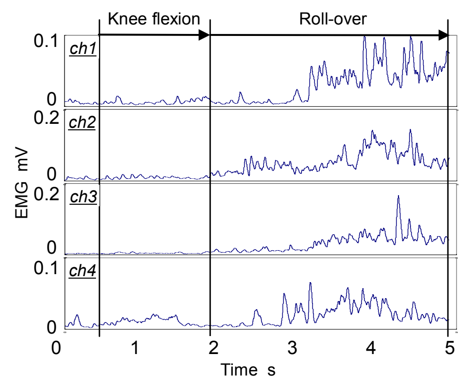

Fig. 12. EMG of EO muscle in LLFT.

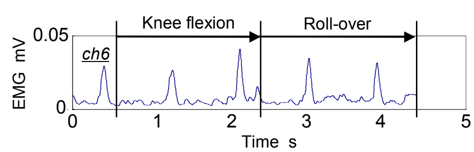

Fig. 13. EMG of RA muscle in LLFT.

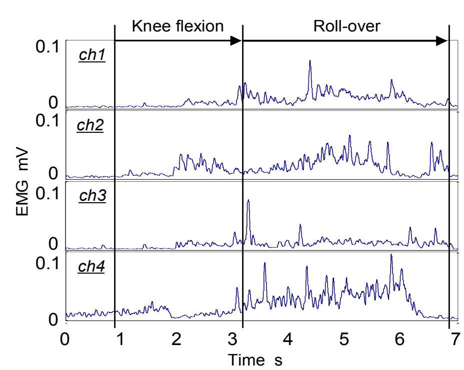

Fig. 14 EMG of IO muscle in LLFT.

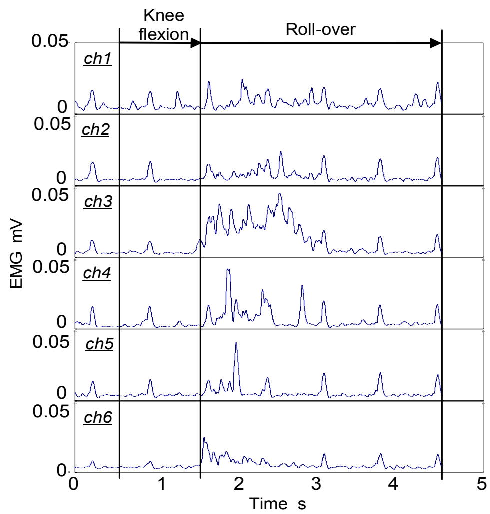

Fig. 15 EMG of EP muscle in LLFT.

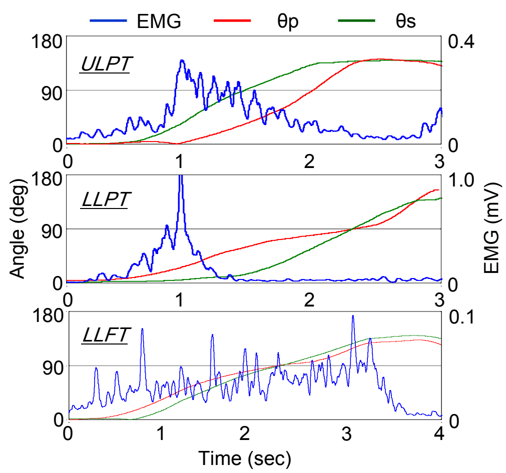

Fig. 16. Relation between EMG and angles at an early stage.

VI. Conclusion and Future Work

We cover patients with cancer bone metastasis, who have a very short time to live. Specifically, we suggest the use of the equipment to support roll-over without fear of spinal fractures and pain caused by pressure on the spine.

In this paper, we described the EMG signal, which was the input signal to support the roll-over. Firstly, we categorized the roll-over into ULPT, LLPT and LLFT, and conducted kinematic analysis. This experiment revealed that the shoulder and pelvis angles differ in the three types. Next, an EMG experiment was conducted. The RA, EP, EO and IO muscle were measured.

Following this experiment, the IO muscle were active at an early stage of roll-over motion, although IO muscle attracted less attention in previous research because they are present at a deeper layer than EO muscle. Besides, these signals were generated before the strongest burden movement on the patient's spine, which was that to buoy the trunk and rotate the pelvis. Therefore, these signals could be used as the input signal of equipment to support the roll-over movement.

In future, we shall apply this result to develop a mechanism and means of support for the equipment, and then aid the roll-over movement as part of terminal care with engineering in mind.

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