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Wearable Echography Robot for Trauma Patient

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***Abstract*— The purpose of this report is to propose a diagnosis and treatment scenario by assistance of bystander and echography robot for trauma patient. Quick treatment is important for patients who have shock by internal bleeding. Therefore, focused assessment with sonography for trauma (FAST), which is a simple and quick diagnostic method, was developed as a first lifesaving step in a hospital. However, a shock patient has little time, and transportation to a hospital may take too long. Therefore, we aim at development of a system which enables FAST at injury scene by assistance of bystander. To develop the system, life-saving flow and a FAST device are significant issues. First, we constructed a diagnosis and treatment scenario. Then, we developed a tele-echography robot system which has 4-DOF that a bystander could attach. This robot is attached to each roughly FAST areas of patient body by a bystander and remotely fine-tuned position by a doctor in a hospital. In this way, a bystander may not do an exact positioning. In addition, the robot has a mechanism to generate contact force between echo probe and patient body surface by two springs. This mechanism not only fit in patient body motion but also reducing the number of controlled axis. To confirm the medical applications of the scenario and the robot, we performed experiments with some examinees and doctors. We confirmed effectiveness of the mechanism and that a bystander could attach the robot to each roughly FAST areas of patient body. We also confirmed that a doctor could do FAST with the robot by remote-controlled on the roughly FAST areas in approximately three minutes. These results show that the robot would enable FAST by assistance of bystander, and the scenario would make FAST faster than the time required transporting the patient to the hospital.**

I. Introduction

If a person receives a severer body impact due to traffic accident or a wide-scale disaster, it is important to treat for traumatic shock patient. The symptom of shock indicates the bad state that is caused by internal bleeding. Quick and appropriate treatment is required for shock, because the patient almost certainly have internal bleeding. In current emergency medical treatment, focused assessment with sonography for trauma (FAST) is widespread as the first step for diagnosingting of your paper. If your paper is intended for a conference, please observe the conference page limits. traumatic shock patient, as shown in Fig.1. FAST is an inspection method for hematothorax, the intra-abdominal blood, and cardiac tamponade that causes shock [1]-[3]. The

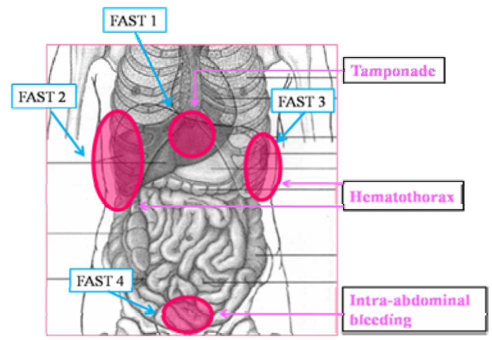

Fig.1 Searching part for FAST

FAST narrows the diagnosis areas down to four parts, regardless of the specialized field the doctor has. Therefore, FAST makes quick and easy diagnosis possible [4]-[6].

On the other hand, death due to a non-life-threatening injury is called preventable trauma death (PTD) [7]. The number of total injury deaths in Japan in 2000 was 3,866 according to the lifesaving first aid center investigation, those from cardiopulmonary arrest on arrival (CPAOA) was 2,012, 52.1% of the injury deaths except CPAOA were PTDs, and they occur frequently [7], [8]. Moreover, 66% of PTDs occur in the emergency room as a result of the time it took investigating the scene of incidence, the cause of injury, and the delay and lack of shock treatment. In other words, it takes a long time to mobilize the ambulance and transport the patient, though there is an effective technique namely FAST for diagnosing the shock patient. Therefore, a remote-controlled echography diagnosis system that any person in the vicinity of injury site (bystander) can easily use may be expected to improve the survival rate of the victim greatly by using this important time until the ambulance arrives.

In recent years, many tele-echography robot systems are developed. Master-slave echography system demands an appropriate contact force for echography probe to patient's body, so some methods to feedback the contact force between the probe and the patient to operator (doctor) [9]-[12] have developed. In addition, portability and skillfulness as the entire system is important, previous tele-echography robot system is discussed around the method to install an ambulance and to control degree of freedom of the probe [13]-[19]. But their scope is limited to a hospital or ambulance scene there is a person who knows usage of the system well.

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Therefore, we aim to develop a diagnosis and treatment system for shock patient that can be used by a bystander at the injury scene. In this paper, we focus on remote-controlled FAST robot that is a terminal of the system, and report FAST robot that can be attached by bystander to the patient

II. Design Approach

A. New diagnosis and treatment flow for shock patients

1) Present flow for shock patient: A shock patient's diagnosis and treatment can be roughly divided into the three following phases:

1. Searching of blood pool areas (FAST)
2. Blood aspiration from the blood pool area by drainage (Revival)
3. Hemostasis by surgical operation (Foundation treatment)

Because a blood pool presses internal organs and increases the risk to the patient, it is important to quickly perform phases 1 and 2. Therefore, we focused on these phases in producing our system, and constructed a diagnosis and treatment flow for use at the injury scene.

2) Construction of new diagnosis and treatment flow: We introduce a new viewpoint support of bystander, as shown in Fig.2, and constructed a medical treatment scenario from the victim's discovery to FAST diagnosis and revival as follows:

1. A bystander transports a portable emergency lifesaving unit attached FAST robot set up in the town to the scene, and establishes communication with a doctor in a hospital using the speaker-phone and camera monitor installed in the unit.
2. The bystander confirms the procedure of a setting of the robot, and places an echo probe of the robot in a rough position of FAST area.
3. The echo probe is placed in a more accurate position by remote-control, and FAST is executed.
4. Steps 2 and 3 are repeated for each FAST area.
5. The bystander installs a device for drainage separately prepared in the emergency unit, and revival treatment is performed if necessary.

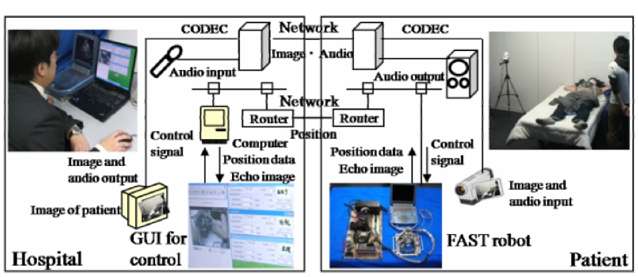


Fig.2 Overview of the FAST robot system

The point in this scenario flow does not only enable to treat at the scene but also enable a bystander to roughly position the echo probe and the doctor to accurately adjust the probe position for the diagnosis by the doctor's remote-control. As a result, a bystander might attach the FAST robot to a patient easily, because exact positioning relied on remote-control by the doctor.

B. Functional demand for the FAST robot

To achieve the above scenario, it is necessary to have functions for the FAST robot as follows:

1. It is possible to attach the robot by bystander.
2. It is possible to do FAST by remote-control on rough position where the bystander attached.
3. It must adapt to the patient's body movements.
4. It must be small and portable.

C. Basic structure of FAST robot

1) Proposal of body-trunk set up: As a type of the FAST robot, we could select ground-based set up used in the research [13]-[19] or body-trunk set up. Even if there is body movement, adaptation of the robot could be improved by the fact that the patient does bear the load of the robot because the body-trunk set up grounds the patient's body. Therefore, we selected the body-trunk set up for FAST robot, and experimented to verify effectiveness of that.

2) Attaching experiment with examinees: The purpose of this experiment is to show results of attaching time and attached position by examinees. We discussed availability of attaching, degree of freedom composition and range of motion of probe based on these results. A patient's body type is a key indicator for how the robot should be attached. So, we classified patient's body type into three (slender, normal height and build, and overweight) based on the BMI index (Table I). Moreover, we think that the age of the bystander could not be limiting since young and elderly people can be bystanders. We conducted an experiment on examinees (bystanders, patients). In this experiment, we used a model attached to the body-trunk with the buffer made of the urethane material and the corset made of silicon to verify attached time and attaching position, as shown in Fig.3.

TABLE I
Classified body type by using BMI

BMI index *1	Body Type
～19	slender
20～23	normal height and build
24～	overweight

*1 BMI index = weight / $(\text{height})^2$

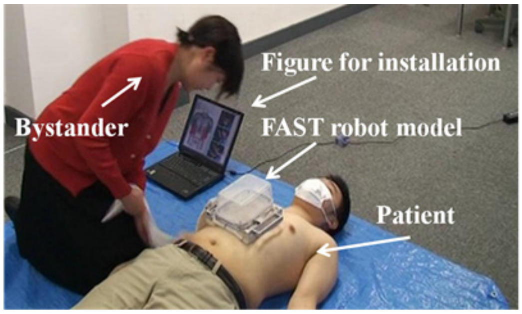


Fig.3 Attaching experiment with bystander

1. ***Methods:*** The bystander attached the model on each patient body looking at attaching position and procedure as shown in Fig.4. Attaching reference position is based on the nipple line (FAST1, 2, 3) or umbilici line (FAST4) so that even non-medical staff like bystander might understand. In addition, there is patient's body motion by his breath. We acquired the attaching time and attached position data from observing placing of the model through to completion. The best attaching area of the model is assumed to be the area can be diagnosed by the doctor's remote fine-tuning.

2. **Results and Discussion*:*** We can see from Fig.5 that it takes long time to attach the FAST robot model to the overweight. This factor seems likely that time is required to wrap the corset to overweight patient's back. But we could confirm that the mean attaching time was approximately 3 minutes, 5 minutes tops. Also, patient's body motion by his breath might not affect attaching time, because the corset is stretchy belt and bystander uses it easily. Meanwhile, maximum gaps between attaching position by bystander and reference line are shown Table II. Fig.6 shows reference lines and directions. There was no one that it was not possible to attach the model to the patient. We consider that using landmarks, such as the nipple line and umbilici line, would be effective for attaching the model.

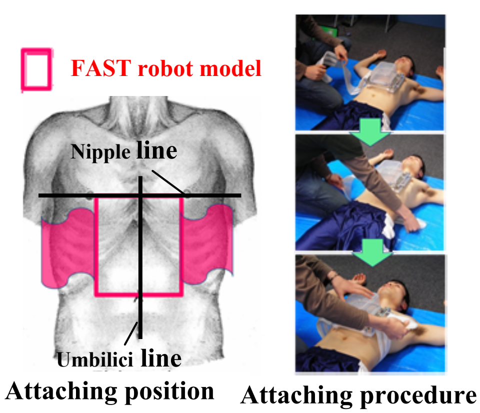


Fig.4 Attaching position and procedure

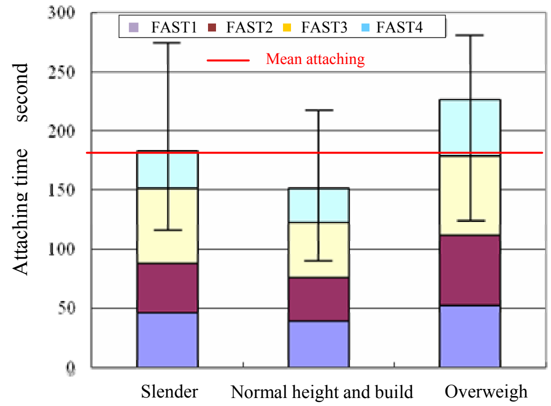


Fig.5 Attaching time to each body type (N = 20)

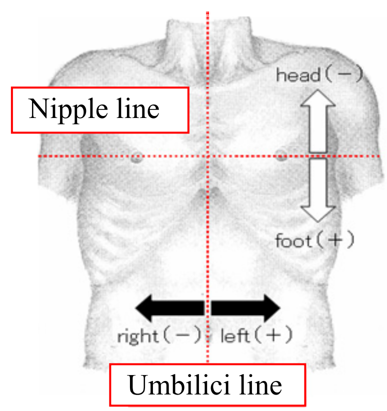


Fig.6 Landmark on body surface

TABLE II
Attached position by bystander (Maximum gap)

	FAST 1		FAST 4	
	left cm	right cm	left cm	right cm
slender	3	-1	1.75	-2
normal height and build	2.25	0	0.5	-0.75
overweight	0.5	-2	2.5	-1.25

	FAST 2		FAST 3	
	head cm	foot cm	head cm	foot cm
slender	-1	5	-2.5	5
normal height and build	-1	6	-1	8
overweight	-0.5	2.5	-0.5	4

As shown in Table II, maximum gap is 3 cm in FAST1, 4 and 8 cm in FAST2, 3. As these attaching point results, we decided degree of freedom composition and range of motion of FAST robot with probe. In addition, we worked out mechanism to reduce the number of controlled axis, because the robot must be minimized.

D. Degree of freedom composition of FAST robot

Controlling the position of the echo probe basically requires six degrees of freedom, as shown in Fig.7. On the other hand, it is necessary to ascertain a minimum degree of freedom for miniaturization. First, one degree of freedom is necessary to move the direction of the body axis to avoid the ribs which are obstructive for FAST. Moreover, the degree of freedom in the vertical direction of the body surface is also indispensable to press the probe against the body surface. On the other hand, the yawing and horizontal movement against the body axis could not be required from the result of attaching experiment, because dealing with these motions could be unnecessary. We described hereinafter in verification experiment.

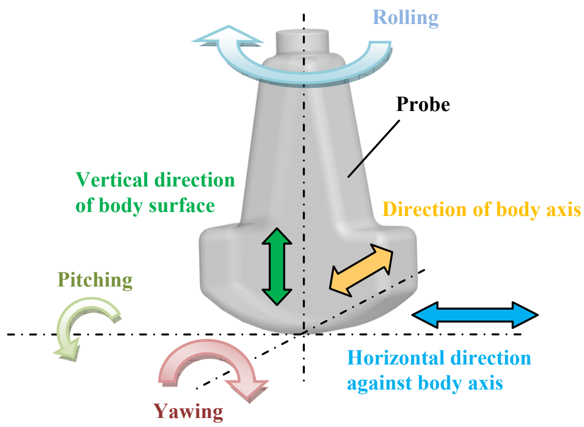


Fig.7 Motion of probe based on patient body axis

E. Remote-controlled FAST robot

We developed FAST robot based on the examination of degrees of freedom, as shown in Fig.8. Next, we determined the degrees of freedom concerning the remote-control from the viewpoint of further miniaturization as follows:

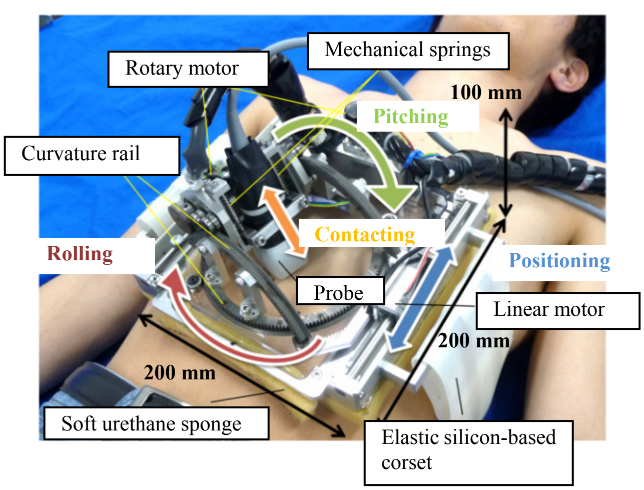


Fig.8 Wearable robot for traumatic shock patients

1) Degrees of freedom operated remotely: The design of the robot was advanced based on the results of the degree of freedom composition of FAST robot. We designed the control system to adjust to one degree of freedom in the direction of the body axis and two degrees of freedom (the pitching and the rolling) so that a doctor in the hospital can accurately perform FAST after the bystander attached the robot on the patient. Because the center of rotation of pitching and rolling have to be the points of the probe on method of operating probe in ultrasonic diagnosis, we combined the gimbals mechanism and curvature rails.

2) Degrees of freedom not operated remotely: The pressing power of the probe closely related to the clarity of the echo image, and when pitching and rolling, should maintain contact force within an appropriate range in response to diagnosis point [12], [19]. On the other hand, if the degree of freedom that can be controlled in the vertical direction of the body surface is installed, the robot would have to be large, and operation at the scene and attaching on the patient would be difficult. Therefore, we developed a mechanism for generating the contact force of the probe and to maintain it with two springs, as shown in Fig.9. The contact force could be generated using this mechanism even with the irregularity, rolling, and pitching of the body surface. In addition, when the patient moves, it could absorb the movement. We conducted an experiment to determine a stiffness coefficient that generates an appropriate contact force when attaching the robot on FAST areas.

1. Methods: First, we experimentally set the stroke of two springs to 10 mm. Next, we obtained some echo image of each FAST area of patients by with three body types while changing stiffness coefficient. A doctor selected the best image for diagnosis, and we selected the spring that was able to produce that image.

2. Results and Discussion: The results of the acquired echo image are shown in Fig.10. When the stiffness coefficient was low, the contact force weakened and the echo image was indistinct. On the other hand, when the stiffness coefficient

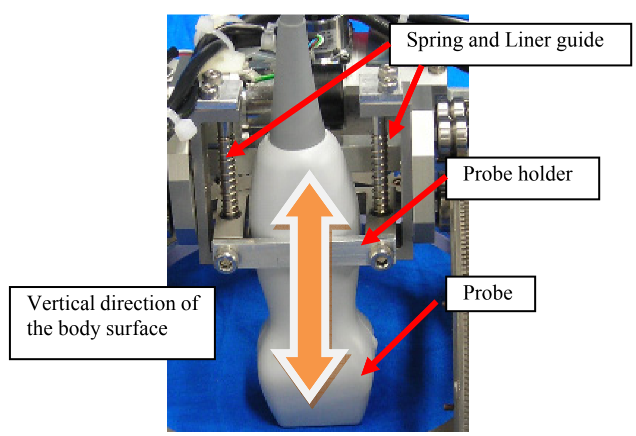
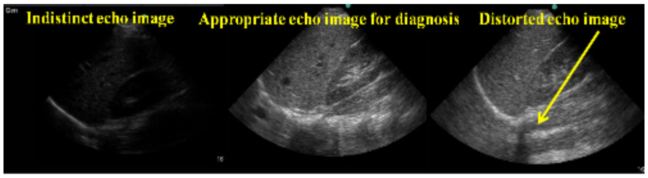


Fig.9 Spring mechanism for adjusting fitness of probe with body surface

was too large, the body surface was distorted, and the echo image was also indistinct. We confirmed the effectiveness of installing two springs that can generate a pre- ssing power of 5.4 N from these results and doctor's opinions about our FAST robot. Also, the robot is 200×200×120 mm, and weight of 2 kg.



Weak contact   Contact force of about 5.4N   Strong contact force

Fig.10 Echo image obtained by experiment for selecting spring

III. Experiments and Results

A. Experiment that verify adaptability to body movement

1) Methods: We tested whether there was deterioration in an echo image when our robot placed on three volunteers (B-MI: 28, 22, 18) who pretended to experience rough breathing and coughing fits.

2) Results and Discussion: There was no deterioration in the echo images, and a diagnosis was possible even when th-ere was a body movement, as shown in Fig.11. Therefore, the generation of the contact force by two springs and with the body-trunk set up might effective.

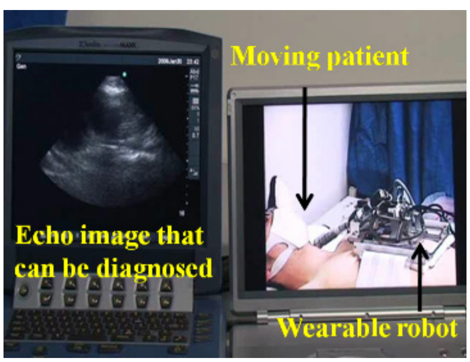


Fig.11Experiment result verifying adaptability to body movement

B. Experiment on FAST with doctor operation

1) Methods: We delimited the patient and the doctor, and prepared the experimental condition enabling sending and receiving of information using only a camera, an echo image, and control signal of the robot. Next, the robot was placed on attaching position which have maximum gap determined during the attaching experiment with examinees. The doctor remotely fine-tuned the probe, and we measured the time to diagnose each FAST area, as shown in Fig.12

2) Results and Discussion: As a result, we confirmed that FAST can be completed in approximately six minutes, as sh-own in Fig.13,14. This result shows the possibility that FAST can be conducted using our robot faster than with current sys-

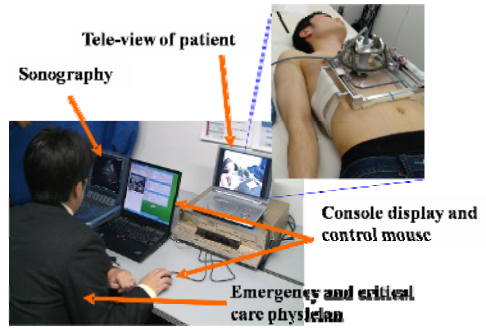
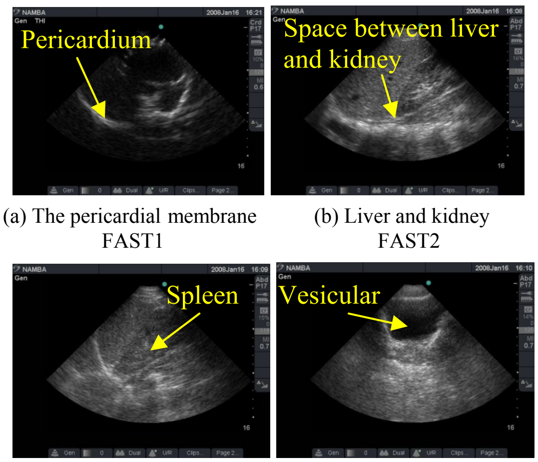


Fig. 12 Experimental condition

tem. We also confirmed that two springs absorb movement due to the irregularity of the body surface and the influence by the upheaval of patient's rib, and the doctor keeps acquiring appropriate echo images without yawing and horizontal movement of the robot.



(a) The pericardial membrane FAST1   (b) Liver and kidney FAST2

(c) Surroundings of spleen FAST3   (d) Vesicular FAST4

Fig.13 Echo images created by FAST robot

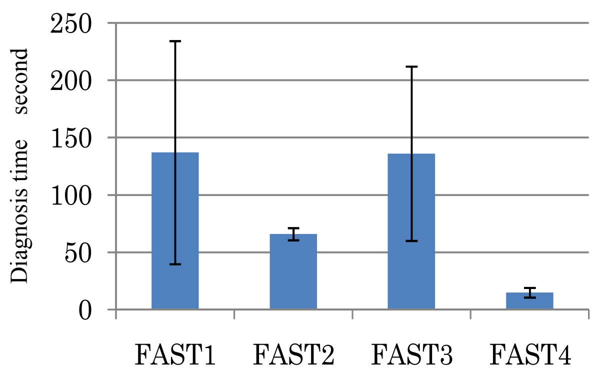


Fig. 14 Diagnosis time (N = 5)

IV. Conclusions and Future Works

We focused on FAST that the retrieval of the cause of shock is possible, and constructed a medical treatment scen-ario with a bystander. In this paper, we constructed a scenario for remote shock diagnosis and treatment with the support of a bystander at the scene and a doctor at a hospital. Next, quick diagnosis was achieved by combining rough positioning by a bystander and remote fine-tuning by a doctor at a hospital. And the robot with a body-trunk set up was developed to fill the demand for achieving the scenario, and a mechanism for generating the contact force using two springs. As a result, adaptability to body movement and miniaturization were achieved. In our experiments, adaptability and the diagnosis performance with body movement were verified. An echo image good enough for diagnosis of FAST was obtained by comparing the placement and diagnosis times with current ambulance transportation time [20], we found that diagnosis and treatment time could be greatly reduced using our system, as shown in Fig.15. The case where the portable emergency lifesaving unit is put on whole town at intervals of 300 m is assumed; we set for transportation of robot time at three minutes. And placement time and FAST time by remote-control are based on results of maximum time of attaching and diagnosis time, as shown in Fig.5 and 14. We also confirmed that time remaining is 17.5 minutes. This result shows a possibility that it is possible to treat for the remaining time for the shock patient.

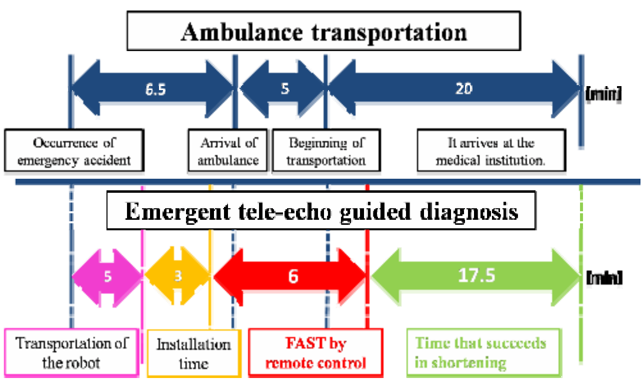


Fig.15 Comparison of time required for ambulance transportation and remote-controlled robot system

The goal of this study is to reduce the FAST time more and design a portable robot system that can be attached safely by any bystander. In this paper, an attaching corset has to be wrapped around the patient's torso to fasten the robot to the patient's body. It seems likely that the FAST time would be increased. Moreover, if injury level of patients is very high, the corset might not be used for patient's safety. For future work, we will develop a new method to attach the patient not to wrap around the patient's torso. On the other hand, it is demanded to drain blood pool after FAST, because the pool presses internal organs and increases the risk to the patient. We think that the survival rate for traumatic shock improves if not only FAST but also the blood pool can be drained while transporting the patient. Therefore, we will also develop robot technology for revival by drainage while the patient is transported.

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