COMPUTER SIMULATION OF NEEDLE VENEPUNCTURE FOR THE DEVELOPMENT OF AUTOMATIC BLOOD SAMPLING SYSTEMS

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***Abstract*-To achieve automatic needle puncturing for automatic blood sampling, we studied peak waveforms of the puncture forces developed during penetration of a blood vessel. Computer simulations of controlled needle puncture were performed using data from experiments on puncturing a rabbit's ear vein. Reproducible results of successive puncturing suggested that this simulation could be applied to the control of needles used for automatic blood sampling.**

***Keywords* - blood sampling, needle, venepuncture, simulation**

I. INTRODUCTION

Automatic blood sampling systems, combined with automatic blood testing systems, may help decrease the volume of blood sampled and assist the development of self-administered home blood testing. Automated blood vessel sampling may also be applicable for drug injection and catheter insertion. We have developed equipment for measuring the forces acting on a needle tip parallel to the puncturing direction, as part of an automatic blood sampling system [1,2]. We carried out experiments using automatic needle puncture of a rabbit's ear vein, monitoring changes in the puncturing forces developed during tip penetration, and confirmed the reliability of this system using computer simulation.

II. METHODOLOGY

1) *Equipment:* Fig. 1 shows the experimental device for measuring the puncturing forces applied to a blood vessel. A force sensor and a disposable tube were installed on the device. The axial force of puncture acting on the needle tip was transmitted to the force sensor through the small linear stage, and the output of the force sensor was sampled every 10 ms. The force measurement device was set on a three-dimensional linear stage, linked to a control-pad. Disposable needles with an outer diameter of 0.40 mm and a length of 19 mm were used for puncturing. The speed of penetration of the needle was set to 2.5 mm/s and the angle was adjusted to 15° to the skin.

Fig.1 Experimental setup for the measurement of puncturing force.

2) *Subjects*: The experiments were performed on five Japan White female rabbits, weighing 1.7–4.5 (2.54±1.17) kg. The experiments were designed to minimize pain, in conformity with the guidelines for animal experiments at Tokyo Medical and Dental University. The veins were dilated to about 1–1.5 mm outside diameter by pressure using a bandage.

3) *Experiments and simulations*: Five experiments of needle puncturing were performed on each rabbit. Penetrations were stopped when the operator confirmed that the needle tip had entered the vein successfully, by observing blood flowing into the disposable tube. An algorithm was developed that detected the peak of puncturing force developed as the needle tip pierced the blood vessel. This algorithm stopped the needle movement when the sampled puncturing force turned negative. To reject noise superposed on the waveform of the puncturing force, a second-order low-pass filter (2^{nd}LPF) was applied to the sampled data. The parameters of 2^{nd}LPF, such as the cut-off frequency (f_c) and the damper coefficient (C_d), were optimized to minimize the peak detection time using the results from the animal experiments.

III. RESULTS

The waveforms resulting from puncturing forces in all trials are shown in Fig. 2. Blood flow into the needle was observed in all cases. Some waveforms have been superposed, such as those for rabbits A and C. Typically, a peak was observed in the puncturing force waveform, and results are shown in Table 1 and Table 2. The peak forces and durations were 0.095–0.280 (0.173±0.045) newtons and 1.540–3.53 (2.263±0.573) s, respectively. A loose linear relationship was obtained between the peak force and the duration as shown in Fig. 3. Both parameter f_c and C_d of 2^{nd}LPF were optimized to 0.5. The durations for peak force

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Abstract

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detection ranged from 0.01 to 0.290 (0.096±0.072) s, as shown in Table 3. No significant differences in duration were observed between the subjects.

IV. Discussion

We propose here a method for detecting the moment of needle puncture into a blood vessel by measuring the changes in force acting on the needle tip. Successful puncturing of the vein was achieved in all cases using automatic needle control simulations. These reproducible results suggest that measuring the forces developed during puncture may be applicable to automatic blood sampling.

The needles were inserted 0.239±0.181 mm into the blood vessel during the detection of peak forces. This was equivalent to 0.062±0.047 mm of sagittal movement in the blood vessel. These needle movements were not serious enough to rupture the blood vessel, which was about 1 mm in diameter. It is important that the needle tip should not pierce the opposite wall, particularly if the vessel has a small radius.

V. Conclusions

The blood sampling needles could be stopped automatically by measuring the vessel puncturing force using data from animal experiments. Thus, the ability to monitor the puncturing force will be applicable to achieving automatic blood sampling.

Acknowledgments

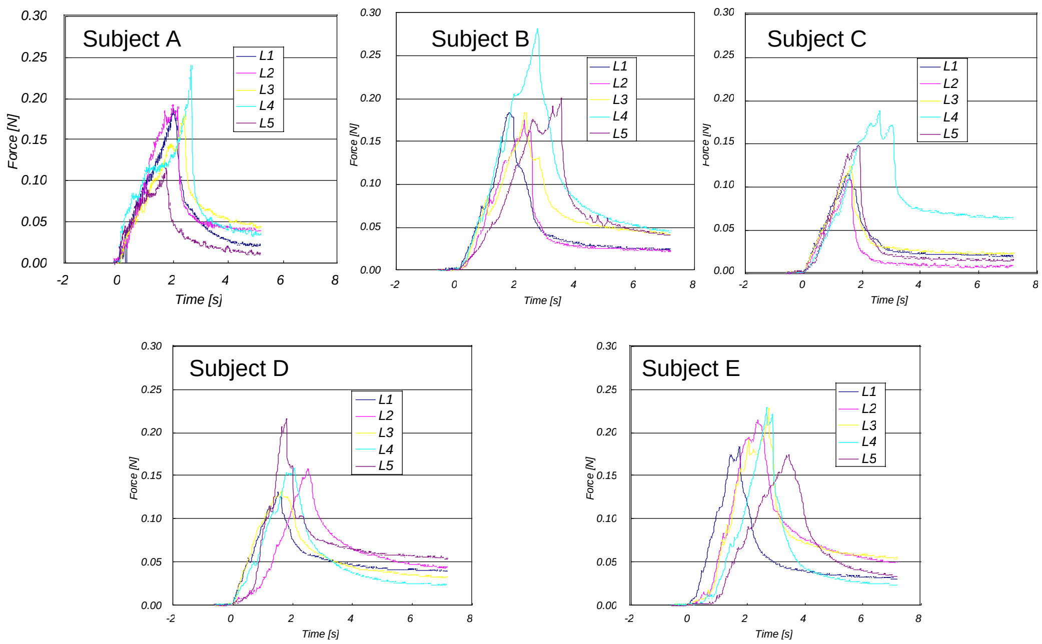

Fig.2 Puncturing force waveforms in each subject.

Table 1 Peak force developed during puncture.

		A	B	C	D	E	AVG ±SD
Peak force (N)	L1	0.188	0.184	0.098	0.131	0.184	
	L2	0.190	0.162	0.109	0.157	0.215	
	L3	0.181	0.184	0.124	0.132	0.228	
	L4	0.240	0.280	0.171	0.158	0.221	
	L5	0.095	0.200	0.148	0.162	0.174	
	AVG	0.178	0.202	0.130	0.148	0.204	0.173
	±SD	0.052	0.046	0.030	0.015	0.024	0.045

Table 2 Durations of the peak force from the beginning of puncturing.

		A	B	C	D	E	AVG ±SD
Duration to the peak (s)	L1	2.00	1.76	1.75	1.54	1.74	
	L2	2.16	2.49	1.54	2.51	2.37	
	L3	2.40	2.35	1.62	1.65	2.76	
	L4	2.66	2.71	2.98	2.08	2.87	
	L5	1.77	3.53	1.87	2.01	3.46	
	AVG	2.198	2.568	1.952	1.958	2.640	2.263
	±SD	0.346	0.643	0.588	0.385	0.637	0.573

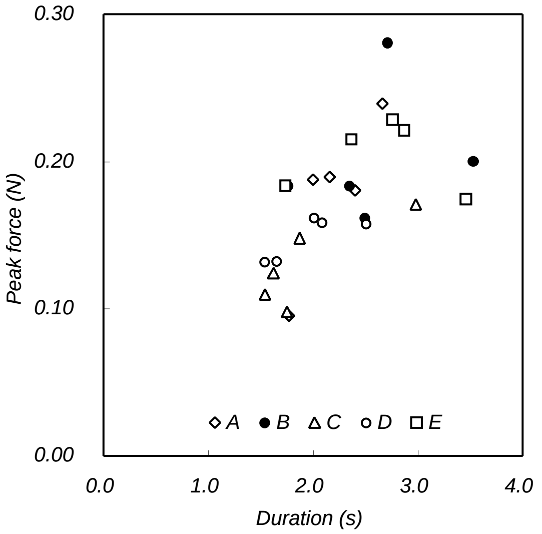

Fig.3 Relationship between peak forces and durations during puncturing.

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Table 3 Durations of detection of peak forces and distances moved by the needles.

		A	B	C	D	E	AVG ±SD
Duration (s)	L1	0.15	0.21	0.05	0.15	0.07	
	L2	0.02	0.04	0.12	0.18	0.20	
	L3	0.04	0.10	0.07	0.29	0.03	
	L4	0.04	0.10	0.10	0.10	0.03	
	L5	0.03	0.01	0.06	0.03	0.17	
	AVG	0.056	0.092	0.080	0.150	0.100	0.096
	±SD	0.053	0.077	0.029	0.097	0.080	0.072
Carried distance (mm)		0.140	0.230	0.200	0.375	0.250	0.239 ±0.181
Depth (mm)		0.036	0.060	0.052	0.097	0.065	0. 062 ±0.047