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Oswestry Disability Analysis of Fuzzy Control Multi-cup Electric Cupping System

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ABSTRACT

A multi-cup electric cupping system (MECS) was proposed, based on the ancient cupping method. MECS consisted of several cups that could be used simultaneously to treat 85 lumbago patients. Each cup was equipped with its own pump and pressure-monitoring system. The vacuum pressure of the cups was controlled using fuzzy logic. Through automated control of the vacuum pressure, long-term relief of muscle tightness was achieved. To develop a scientific foundation for this alternative treatment, we compared the Oswestry Disability Index (ODI) scores from conventional basic cupping to the ODI scores for our proposed MECS. The ODI scores using MECS decreased from 11.71 ± 1.61 before treatment to 4.81 ± 1.48 and 1.87 ± 1.61 after three and five treatments, respectively. The improvement rate in the ODI scores using MECS after three treatments was higher than that achieved by basic cupping. These results, combined with the convenience offered by enhanced information technology and fuzzy logic capabilities, should increase the efficiency of this device, and facilitate the opportunity to further explore the potential of Oriental medical practices.

Key words: Oswestry Disability, Fuzzy Logic, Lumbago, Cupping System, Information Technology

1. INTRODUCTION

Expedited by newly developed technologies and the needs of an aging population, the healthcare industry is quickly becoming an increasing fraction of national economies in most Organization for Economic Cooperation and Development (OECD) countries. In addition, the convergence of existing industries with information technology (IT), biotechnology (BT), nanotechnology (NT), and environmental technology (ET) is emerging as the next-generation core technology. As a result, the demand for ubiquitous healthcare is also increasing. Significant advances in medical device technology have been realized, with a focus on information and communication technology and large medical care-related companies. However, herbal treatment technology and alternative medical practices have not met with the same commercialization success, due to a lack of understanding of Oriental medical practices[1-3]. Although most herbal treatments are not based on advanced technologies or advanced medical principles, many consumers could possibly benefit from such treatments. Concerns that Oriental medicine falls short of the scientific verification system of Western medical sci-

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ence have been raised continuously. However, developed countries are doing their best to build a scientific verification system to test the stability and effectiveness of herbal treatments through basic clinical research. The development of IT technology and the demand for new medical services are driving forces behind ubiquitous healthcare [6-8], and they have facilitated the development of treatment verification controls.

An example of traditional Chinese medicine is cupping therapy. In this treatment, suction is applied to the patient's skin in an attempt to increase blood flow to certain areas, such as muscular tissue and joints, to promote healing [9]. In this study, we developed a multi-cup electric cupping system (MECS); using this system, basic treatment can be carried out primarily via self-diagnosis and a patient self-care guide. The pressure inside the cups was established using a solenoid valve to control the flow of pumped air from a pump motor. To control the pressure more precisely, fuzzy logic control was applied to the pumping motor generating air flow into the cups. For our MECS, the Oswestry Disability Index (ODI) [10] score was compared before and after three and five treatments. The improvement rate observed for our system after three treatments was significantly higher than that observed after applying conventional basic cupping techniques. In addition, the proposed MECS can use many cups simultaneously, with the pressure inside the cups controlled independently. Tests and analyses confirmed successful treatment using our system, which could potentially lead to greater acceptance and possibly demand for this type of alternative treatment.

2. METHODS

2.1 MECS configuration

MECS consisted of a power subsystem, control subsystem, and driving subsystem. The power subsystem was divided into a switching component that adjusted the system's power supply and an electricity-converting module. The switching component included the system power switch and a time switch for adjusting the operation time. The electricity-converting module was equipped with a controller and an alternating/direct current converter (AC/DC), to supply drive power to the solenoid valve. The control subsystem controlled the suction pump and the solenoid valve by outputting a control signal that depended on the pressure sensor values. The driving subsystem controlled the vacuum pressure of the cups, through analysis of the intake and out-take behavior; the resulting pressure was controlled by a solenoid valve connected between the nozzle and suction pump. Fig. 1 shows a schematic configuration of MECS.

Because the control subsystem used DC power, an AC/DC converter was required to convert the available AC power source. The AC/DC converter converted 220 VAC input into 24 VDC for solenoid valve operation and 12 VDC for the controller. The basic measurement feedback system consisted of three components: the sensor, processor, and actuator. The sensor used a transducer to acquire an energy signature from the targeted (cupped) area of the human body and converted this signal into an electrical signal. Then this electrical signal was sent to the processor. The actuator adjusted the pressure, based on the processed signal received. The sensor was an essential component in MECS system, in terms of diagnostics and closed-loop treatment, and played an important role in determining the performance of the overall MECS.

2.2 Characteristics of MECS

Use of MECS first required initialization of certain system parameters: Set_Time and Set_Pressure, corresponding to the cupping machine operating time and the pressure inside the cups, respectively. After initialization, the Set_Pressure and Set_Time

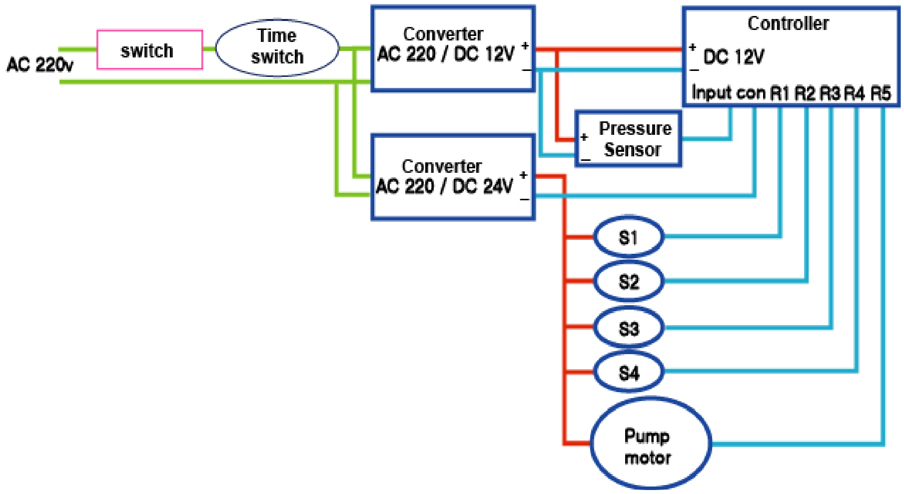

Fig. 1. Schematic configuration of the multi-cup electric cupping system.

of the electric cups were entered, and the internal pressure and operating time of the cups were detected. When comparing the Set_Time and operating time of the cups, if the latter exceeded the former, then the operation of the cups stopped immediately. If not, then the intake valve and out-take valve were adjusted accordingly, as described below.

Control over the settings of the intake and out-take valves allowed MECS to operate in three different modes: (1) intake mode (intake valve: OPEN [1], out-take valve: CLOSED [0]), (2) out-take mode (intake valve: CLOSED [0], out-take valve: OPEN [1]), or (3) pressure maintenance mode (intake valve: CLOSED [0], out-take valve: CLOSED [0]). The cups worked in accordance with the set procedure. Table 1 provides a description of the modes and valve settings.

In the cupping system, each nozzle was equipped with intake and out-take solenoid valves to adjust the vacuum pressure inside the cups. Table 1 provides the operating conditions of the intake and out-take valves, and the resulting MECS behavior. If the intake valve was opened (1) and the out-take valve closed (0), then the air inside the connected cups was pumped out through the nozzle. If the intake valve was closed (0) and the out-take valve was opened (1), then the air inside the connected cups was discharged through the nozzle. If both the intake and out-take valves were closed (0), then the vacuum pressure inside the cups attached to the nozzle was maintained.

Table 1. Operating conditions of the intake and out-take valves and the resulting behavior of the cupping machine

Intake valve	Out-take valve	Cupping machine behavior
(1)	(0)	Intake mode
(0)	(1)	Out-take mode
(0)	(0)	Pressure maintenance
(1)	(1)	Intake, out-take, and pressure maintenance

When the vacuum pump motor is on and pumping out air, it performs intake, out-take, and pressure maintenance by controlling the intake and out-take valves of each nozzle (fourth condition shown in Table 1).

In Fig. 2, because the upper intake valve is open (1) and the upper out-take valve is closed (0), Nozzle 1 pumps out the air inside the attached cup.

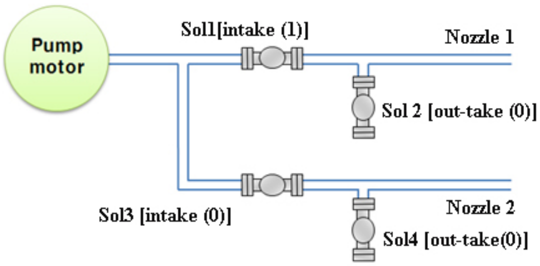

Fig. 2. Intake, out-take, and pressure maintenance of MECS.

With both the lower intake and out-take valves closed (0), Nozzle 2 maintains the vacuum pressure inside the attached cup. When an intake valve is closed and the corresponding out-take valve is open, the air pressure inside the cup attached to the associated nozzle reaches equilibrium with the environment. Intake, out-take, and pressure maintenance was controlled through the solenoid valves using pressure readings obtained from the sensors. The pressure of each nozzle was adjusted depending on the sensor readings from tightened muscles in the targeted cupped area.

2.3 Fuzzy control algorithm for the control of vacuum pressure

Since its inception in 1965, the theory of fuzzy sets has advanced in many disciplines and in a variety of different ways. Applications of this theory can be found, in artificial intelligence, computer science, medicine, control engineering, decision theory, expert systems, logic, management science, operations research, pattern recognition, and robotics. Fuzzy control has the advantage of allowing the use of vague linguistic terms in the rules that control various systems. Also, because it does not provide an exact mathematical model of a system, fuzzy logic can be applied to uncertain systems and various variable speed systems [11,12].

Fuzzy logic is a logic system that deals with uncertainty. Fuzzy variables are composed of sets of values expressed in the form of a membership function, with some value between '0' and '1' (not simply '0' or '1,' as in a standard binary logic systems). All operations of fuzzy control are represented by the operation of this membership function. A fuzzy rule, an important part of the system that influences the performance of the fuzzy controller, is based on empirical knowledge or trial-and-error testing by the designer. In general, the fuzzy rule uses an IF - THEN format, as in the following Fig. 3.

In the Fig. 3, x, y, and z are fuzzy variables, and A, B, and C are fuzzy subsets from the universal sets X, Y, and Z, respectively.

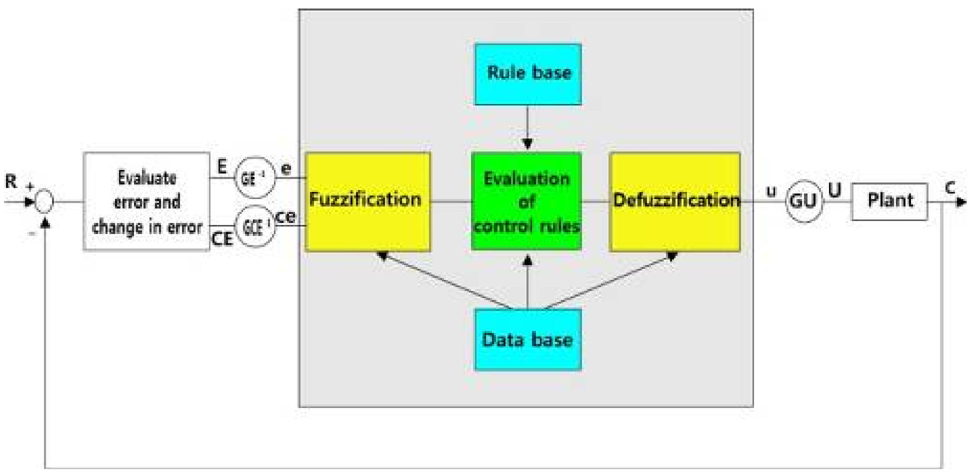

Fig. 3. Basic structure of the fuzzy control system.

$$IF\ (x\ is\ A\ and\ y\ is\ B)\ THEN\ (z\ is\ c) \quad (1)$$

The basic structure of the fuzzy control system is shown in Fig. 3. The control signal U is deduced from the error (e) and the change in error (ce), i.e., two state values. The error(e) and the change of error (ce) are per unit (PU) signals, derived by dividing the actual E and CE signals by each gain factor. The rule base for performing fuzzy control depends on the knowledge of the designer who designs the system.

In our MECS, the vacuum pressure was converted into a fuzzy set before being used; this process is called fuzzification. To control the vacuum pressure of the cupping machine, the error (E) and the change of error (CE), representing the difference between the vacuum pressure inside the cups and the reference signal from the controller, were calculated. If the calculated E and the CE are both large and positive, then the target of the control changes by a significant amount in the positive direction. Therefore, smooth control can be achieved when the change in the control setting (ΔU), an output variable, is also very large and positive. Also, when both E and CE are "zero," both the error (e) and the change in error (ce) are "zero." Therefore, the output variable is also "zero," because control is no longer needed. As shown above, the values configured for the rule base are in the form of IF - THEN statements, as shown in Table 2. If instead, they are expressed in the form of a 7×7 matrix, then they take the form shown in Table 3.

Table 3. Rule base for pressure control, based on the IF-THEN format in Table 2

	NB	NM	NS	Z	PS	PM	PB
NB	NVB	NVB	NB	NB	NM	NS	Z
NM	NB	NB	NM	NM	NS	Z	PS
NS	NB	NM	NS	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PS	PM	PB
PM	NS	Z	PS	PM	PM	PB	PB
PB	Z	PS	PM	PB	PB	PVB	PVB

$E(k)$ corresponds to the column entries.
$CE(k)$ corresponds to the row entries.

Fuzzy logic control can be applied by replacing the conventional proportional-integral (PI) controller and has the advantage that robust control can be achieved, despite changes in the operating conditions. The structure of the selected fuzzy controller handles the two input variables (E) and CE) and the ΔU, which is one of the output variables. The fuzzy control for the vacuum pressure control system of MECS is shown in Table 4.

MECS presented in this paper adjusts the vacuum pressure of the cups via the speed control of

Table 4. Fuzzy control for the vacuum pressure control system

(1) Using the internal vacuum pressure ($Pref$) of the cups measured by the pressure sensor and the reference vacuum pressure of the cups, the E and CE values, which are the input values for fuzzy control, are calculated.

$$E(k) = Pref(k) - P(k) \quad (2)$$
$$CE(k) = E(k) - E(k-1) \quad (3)$$

(2) Then the E and CE values are converted into unit values to use as input values for fuzzy control. This process is called fuzzification.The gain coefficient of each controller is given by

$$e(k) = E(k) / GE \quad (4)$$
$$ce(k) = CE(k) / GCE \quad (5)$$

GE, GCE, and GU are the gain coefficients for each controller.

(3) Using the values of $e(k)$and $ce(k)$, $du(k)$ in Table 4 is determined.

(4) The resulting normal value of $du(k)$ is calculated by non-fuzzification.

(5) The following control signal is calculated:

$$U(k) = U(k-1) + GU * du(k) \quad (6)$$

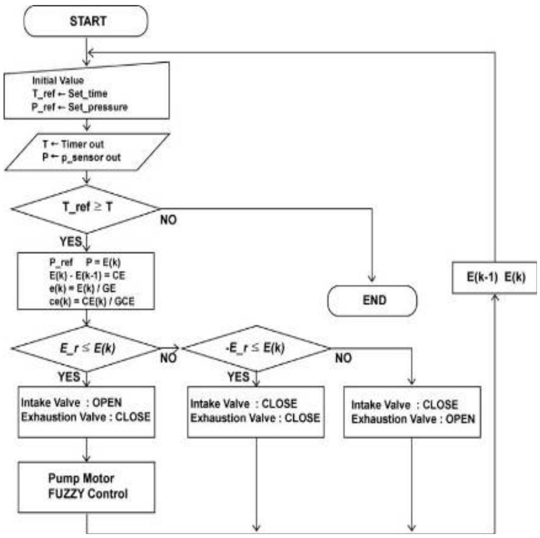

Fig. 4. Control flowchart of MECS.

the pump motor. Fig. 4 shows the control flowchart for MECS.

Fig. 5 (A) and 5(B) show a comparison of the speed control characteristics between the conventional (PI) controller and the fuzzy logic controller proposed in this study for MECS, respectively. Fig. 5(A)-(a) and 5(B)-(a) represent the reference signal generated by the controller, Fig.5 (A)-(b) and 5(B)-(b) represent the speed signal of the controller, and Fig. 5 (A)-(c) and 5(B)-(c) represent the error in the speed signal of the controller with respect to the reference signal. A comparison of Fig. 5 (A)-c and 5(B)-c indicates that the error signal of the fuzzy control scheme for MECS was much smaller than that from the conventional PI controller, suggesting that precise pressure control is possible with MECS.

3. RESULTS

3.1 Subject of study and method of evaluation

This study was conducted on 85 lumbago patients, ranging in age from 20 to 64 years, who underwent treatment in the Department of Acupunc-

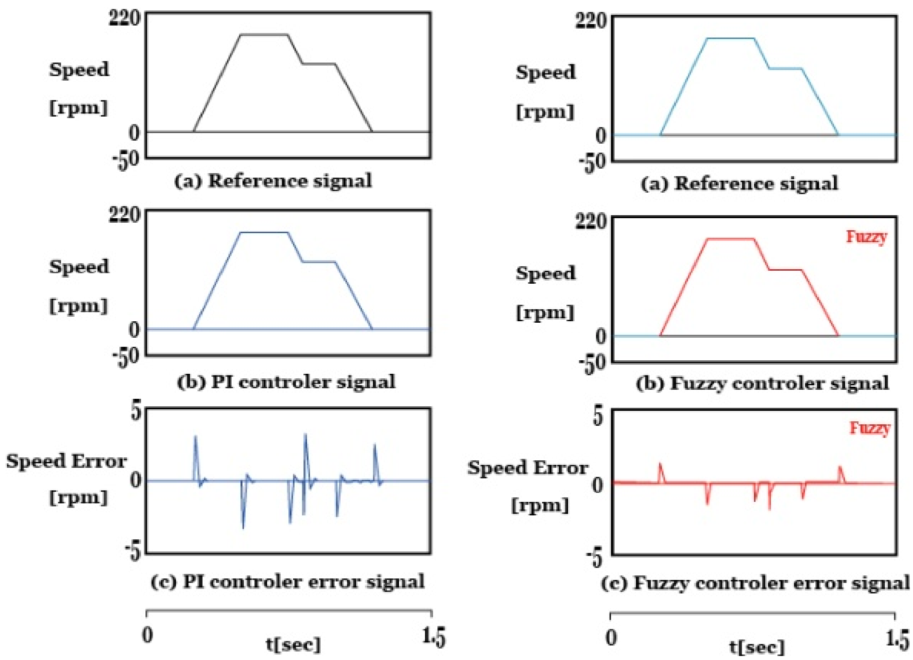

Fig. 5. Comparison of the response characteristics of the pump motor for (A) a conventional PI controller and (B) the proposed MECS fuzzy logic controller: (a) reference signal generated by the controllers, (b) the speed signal of the controllers, and (c) the speed error generated by the controller with respect to the reference signal.

ture and Moxibustion Medicineat Dongshin University Oriental Hospital in Suncheon, Korea between April 1, 2012, and August 31, 2012. The 33 patients were treated using the conventional basic cupping technique; the 52 patients underwent treatment using MECS 5 different times, as often as twice a week. We analyzed the change in the ODI, based on the sex, age, and medical history of patients [13,14].

The ODI is derived from the Oswestry Low Back Pain Questionnaire, developed by Fairbank and Pynsent [10], and is used by clinicians and researchers to quantify disability related to lower back pain. The questionnaire contains specific topics related to the patient's ability to function in everyday life. Within each topic area, the patient chooses among six potential scenarios, the situation that most closely resembles their typical pain and limitations. Then the specific situation chosen is rated from 0 to 5, based on the degree of disability and discomfort, with 5 indicating severe disability. In this study, the ODI before treatment is represented by ODI0, ODI3 corresponds to the ODI after three treatments, and ODI5 represents the ODI after five treatments. The improvement rate in the ODI score is given as follows:

Table 9. Improvement rate in the ODI score following cupping therapy

	ODI3 ′	ODI5 ′
Basic cupping	49.33 ± 15.21	80.51 ± 13.98
MECS	59.25 ± 10.71	84.81 ± 12.41
P-value	0.003	0.146

ODI3′: improvement in ODI score after three treatments.
ODI5′: improvement in ODI score after five treatments.

Improvement rate of ODI = (ODI before treatment − ODI after treatment) / ODI before treatment × 100 (7)

3.2 Analysis and results

We used SPSS12.0 for Windows for statistical analysis of the results. Every data point is represented as the mean ± standard deviation. Pearson's chi-squared test was used to evaluate the two patient groups based on their sex and outbreak day of the illness. One-way repeated-measure analysis of variance (ANOVA) was used to analyze the changes in ODI scores within a group. Mann - Whitney testing and nonparametric methods were used to evaluate the ODI scores with respect to age and time of treatment. P-values below 0.05 were considered to be statistically significant. Tables 5, 6, and 7 show the patient distribution for the two groups studied, with respect to sex and

Table 5. Distribution of patients undergoing basic cupping and multi-cup electric cupping therapy, with respect to sex and age

Age		18 - 29	30 - 39	40 - 49	50 - 59	60 - 65	Total	
Basic cupping	M	4	3	4	4	2	17	33
	F	3	2	6	4	1	16	
Multi-cup system	M	6	10	6	7	4	33	52
	F	1	6	4	5	3	19	

M: Male; F: Female

Table 6. Distribution of patients undergoing basic cupping and multi-cup electric cupping therapy, with respect to the degree of lower back pain

	Acute	Subacute	Chronic	Total
Basic cupping	17	7	9	33
Multi-cup system	33	9	10	52

Table 7. Distribution of patients undergoing basic cupping and multi-cup electric cupping therapy, with respect to general characteristics and medical history of the patients

	Sex (M/F)	Age (years)	Duration of onset (acute/subacute/chronic)
Basic cupping	17/16	41.4 ± 11.82	17/6/7
Multi-cup system	33/19	43.5 ± 12.23	33/9/10
p-value	0.025	0.522	0.785

M: Male; F: Female

Table 8. Change in the ODI score following cupping therapy

	ODI0	ODI3	ODI5	P-value
Basic cupping	12.00 ± 1.71	6.13 ± 2.16	2.45 ± 1.93	0.000
MECS	11.71 ± 1.61	4.81 ± 1.48	1.87 ± 1.63	0.000

ODI0: ODI score before treatment, ODI3: ODI score after three treatments, ODI5: ODI score after five treatments

age, degree of lower back pain, and general characteristics of the patients and their medical history, respectively.

Table 8 shows that the ODI score for MECS decreased significantly from 11.71 ± 1.61 (ODI0) to 4.81 ± 1.48 (ODI3) and 1.87 ± 1.61 (ODI5). Table 9 shows the improvement rate in the ODI scores for the two groups after treatment. The rate recorded for MECS and basic cupping method was 59.25 ± 10.71% and 49.33 ± 15.21%, respectively, after three treatments, and 84.81 ± 12.41% and 80.51 ± 13.98%, respectively after five treatments. The improvement rate in the ODI score for MECS was significantly higher than that for conventional basic cupping after three treatments ($p<0.05$).

4. CONCLUSION

Social change in the healthcare and medical industry, driven by the increasing demand for healthcare, an aging society, and elevated expectations for overall healthcare, as well as numerous advances in communication, information, and medical device technology, will determine the future of healthcare. Novel Western medical equipment in the ubiquitous era has relied on advances in IT and communications, as evidenced by the increasing number of large medical care-related companies in the healthcare industry. However, herbal treatment methodologies have not been commercialized to the degree of Western medical technologies due to the lack of understanding of Oriental medicine. Research and development is needed to systematically and scientifically demonstrate the potential of traditional Chinese medical methodologies.

In the present study, we developed the MECS system for traditional Chinese cupping. Most cupping machines require each cup to be applied to different parts of the body one at a time; thus, several regions of the body cannot be treated simultaneously. Using our proposed portable MECS, a patient can carry out basic self-treatment using a self-help treatment guide. In our system, several cups operate simultaneously but independently. Pressure sensors were used to apply the proper vacuum pressure suitable to the physical characteristics of the targeted/cupped area. Proper pressure was achieved using fuzzy logic control, by calculating the error (E) and the change in error (CE) from the differences in the vacuum pressure inside the cups with respect to a reference signal. If both E and CE were very large and positive, then the target of the control was pushed significantly in the positive direction.

We compared the improvement rate in the ODI score between MECS and conventional basic

Table 10. Comparison of conventional basic cupping and MECS

	Conventional electric cupping system	Multi-cup electric cupping system
Adjustment of pressure	Impossible	Possible
Separation of inhaler and cup	Required	Not required
Pressure display	Impossible	Possible
Changes in pressure due to cup shape	Change	No change
Features	Muscular condensation, blistering symptoms, pain response	Resolution of symptoms after procedure, synchronous procedure using multiple cups, each cup controlled independently

cupping. The score for MECS decreased significantly from 11.71 ± 1.61 (ODI0) to 4.81 ± 1.48 and 1.87 ± 1.61 after three (ODI3) and five (ODI5) treatments, respectively. The improvement rate in the ODI score by MECS after three treatments was higher than that using conventional basic cupping. Table 10 provides a comparison of several parameters associated with conventional basic cupping therapy and MECS.

Because the vacuum pressure of each cup is controlled independently, our proposed MECS can treat the patient using a number of cups simultaneously. In addition, the patient/user can adjust the vacuum pressure of the cups and choose the appropriate treatment time to alleviate existing muscle tension and pain. This system may provide a prototype for scientific and clinical testing of Chinese medical practices and alternative health practices, which we anticipate will facilitate greater acceptance and possibly popularization of this and other traditional Chinese medical treatments.

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