Comparative Assessment of Thermal Damage Induced by Bipolar Forceps in a Bovine Liver

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BACKGROUND AND OBJECTIVES: Bipolar electrocautery systems in neurosurgical procedures may induce thermal damage to adjacent tissues, especially neural tissues. Therefore, it is crucial to control thermal spread from the tips of bipolar forceps into adjacent tissues. The goal of this study was to compare the thermal damage induced in unintended adjacent tissues during coagulation with 6 different bipolar forceps.

METHODS: Fresh ex vivo bovine liver tissues were coagulated with 6 different bipolar forceps: Aesculap® nonstick, Atlas Choice™, ISOCOOL®, SilverGlide®, Spetzler™-Malis®, and VersaTru® (45 trials per bipolar forceps). For all forceps, coagulation was performed with a power setting of 35 Malis units, 1-mm tip spacing, and 3-second activation time. Tissue samples were evaluated for the extent of thermal damage (30 trials per bipolar forceps). Tissue temperatures were measured with thermocouples placed in the tissues (15 trials per bipolar forceps). The area and maximum depth of thermal damage were measured manually with image analysis software.

RESULTS: The injury area induced by ISOCOOL® and Atlas Choice™ bipolar forceps was significantly less than that of the Aesculap® nonstick ($P < .001$), SilverGlide® ($P < .001$), Spetzler™-Malis® ($P < .001$), and VersaTru® ($P < .001$). The areas of thermal injury caused by the ISOCOOL® and Atlas Choice™ forceps were not statistically significantly different from each other ($P = .08$). Lesions from the ISOCOOL® and Atlas Choice™ forceps showed significantly less depth of injury than the Aesculap® nonstick ($P = .001$), SilverGlide® ($P < .001$), Spetzler™-Malis® ($P < .001$), and VersaTru® ($P < .001$). There was no statistically significant difference in the depth of thermal injury between the ISOCOOL® and Atlas Choice™ forceps ($P = 1.0$).

CONCLUSION: Bipolar forceps that effectively limit excessive thermal dissipation reduce the risk of unintended injury to adjacent or peripheral tissues. In an ex vivo bovine liver model, coagulation tests with ISOCOOL® and Atlas Choice™ bipolar forceps resulted in less depth and lower mean injury areas compared with other forceps.

KEY WORDS: Bipolar forceps, Coagulation, Temperature, Thermal injury

Bipolar forceps are an essential tool for modern neurosurgical operations.[1-3] Greenwood introduced bipolar forceps in 1942, [4-7] and Malis' significant modification of the two-point coagulation system had a crucial role in the development of the bipolar cautery system used today.[6,8-10] In 1967, Yaşargil introduced microsurgical techniques to repair minor vascular ruptures through the application of bipolar coagulation. This approach involves initially identifying the bleeding site with suction and compression with a pledget, followed by sealing with bipolar coagulation.[11,12] He used a large set of bayonet forceps with different lengths and tip sizes for bipolar coagulation.[13-15]

Targeted coagulation of bleeding vessels close to critical structures is necessary in all surgical disciplines. However, thermal spread from the bipolar tips to untargeted adjacent tissues risks injury to critical structures.[16] Therefore, reducing unintended adjacent thermal injury to neural tissues during bipolar coagulation is critical for neurosurgeons. Other problems with bipolar forceps include tissue adhesion to the tips, the creation of an electric spark between the tips, and tissue charring. Most of these issues are caused by overheating of the forceps tips.[17]

ABBREVIATION: AHT, Active Heat Transfer®.

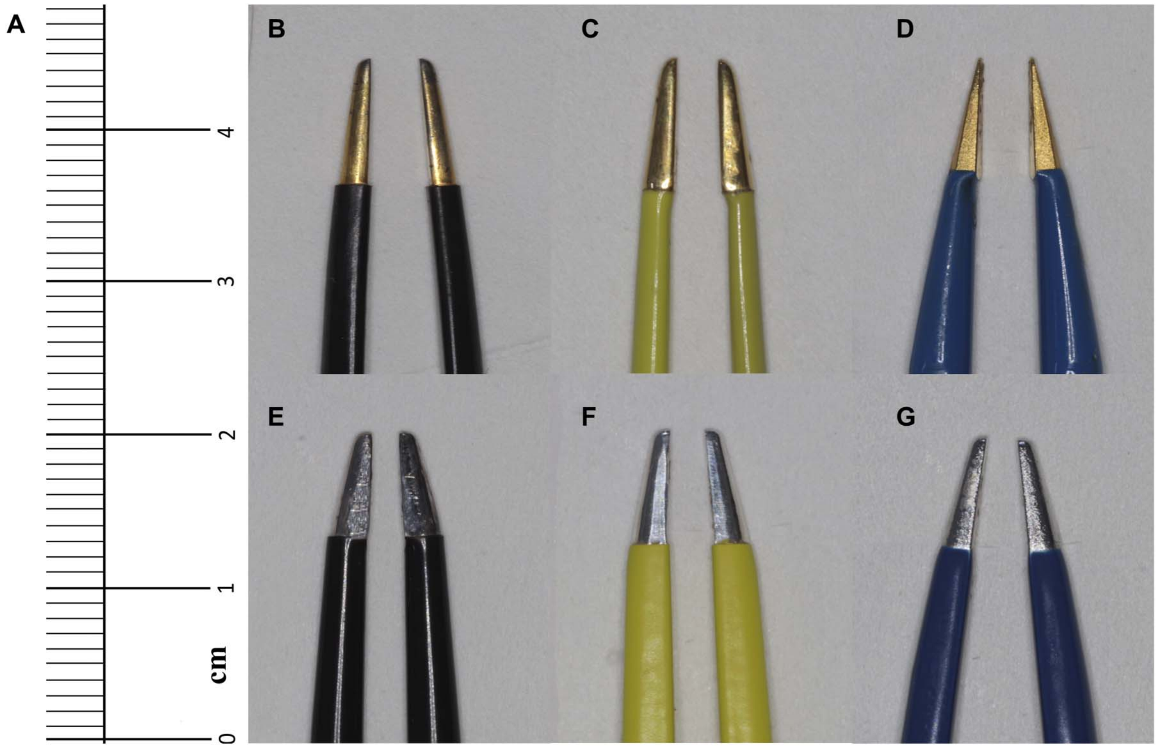

FIGURE 1. *The forceps tips used in this study.* **A**, *The scale for the tips;* **B**, *Aesculap ® non-stick;* **C**, *Atlas Choice™;* **D**, *ISOCOOL ®;* **E**, *SilverGlide ®;* **F**, *Spetzler™ -Malis ®; and* **G**, *VersaTru ®.*

Various methods have been developed to reduce charring and tissue adhesion and to minimize heat transfer away from the bipolar tip, including the incorporation of an irrigation system.[18-20] Different coating materials have been tested on the tips of forceps, including silver,[21] gold,[22] nickel,[23] and titanium. Mikami and associates have evaluated the adherence of the coagulum to the

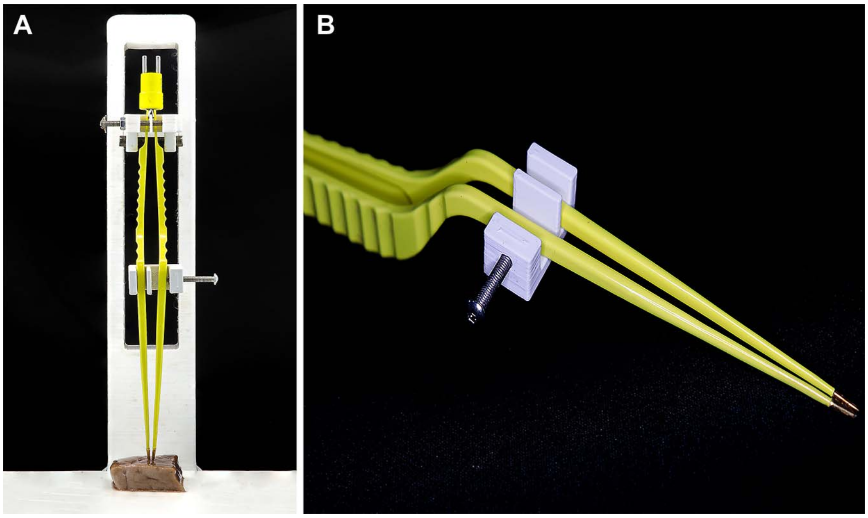

FIGURE 2. *Bipolar forceps showing* **A**, *the vertical holder for coagulation and* **B**, *the tip-spacing fixture.*

FIGURE 3. *Thermocouple needle probes were placed into the tissue at the site of coagulation. A multichannel data logger captured temporal temperature changes up to a depth of 2 mm within the tissue.*

bipolar tip, the histological study of the coagulated artery, and the physical properties of the bipolar tips.[3]

A novel technology, Active Heat Transfer® (AHT), has been introduced. This technology continuously transfers excessive heat away from bipolar tips through fluid-filled heat pipes. AHT has aimed to prevent excessive heat build-up and minimize thermal spread during bipolar cauterization.[24] Elliot-Lewis and colleagues[17] compared the extent of thermal injury caused by coagulation with the ISOCOOL® (Codman & Shurtleff, Inc.), which incorporates AHT, and the traditional NonStick Mirror Finish (Codman & Shurtleff, Inc.) forceps. The Trio Wand bipolar system, which was recently introduced, provides continuous suction and irrigation to maximize visibility during surgery of deep-seated lesions. In a study by Roy and colleagues, the thermal injuries caused by the TRIOwand (NICO Corporation), SilverGlide® (Stryker), and Spetzler®-Malis® (Stryker) bipolar systems were compared using a live porcine brain model.[25]

Our study aimed to compare the thermal profiles during coagulation of 6 different bipolar forceps: Aesculap® non-stick (Aesculap, Inc.), Atlas Choice™ (American Surgical Company), ISOCOOL® (Codman & Shurtleff, Inc.), SilverGlide® (Stryker), Spetzler™-Malis® (Stryker), and VersaTru® (Codman & Shurtleff, Inc.)

METHODS

The study was conducted in the microneurosurgery laboratory at Yeditepe University Koşuyolu Hospital, and received approval from the Internal Review Board of Dr Sadi Konuk Training & Research Hospital in İstanbul, Türkiye (Protocol number: 2023/124, dated March 20, 2023). The procedure does not require patient consent because the study was conducted on *ex vivo* liver tissues. The size of adjacent thermal injury was evaluated after controlled bipolar coagulation using 6 different bipolar forceps: (1) Aesculap® non-stick, (2) Atlas Choice™, (3) ISOCOOL®, (4) SilverGlide®, (5) Spetzler™-Malis®, and (6) VersaTru®. Controlled coagulation and postcoagulation thermal injury measurements were taken by 2 different researchers to prevent bias. The tip size of all forceps was 1.0 mm (Figure 1). All 6 forceps were powered by the same electrosurgical generator, Valleylab Force FX (Covidien), and the power was set to 35 Malis units for all trials. Controlled bipolar coagulation was performed on 180 separate tissue segments of a fresh ex vivo bovine liver (30 trials per forceps).

Histological Tissue Preparation

Coagulation of a fresh bovine liver was performed within 6 hours of slaughter. Tissue specimens were immersed in a temperature-controlled water bath at 37°C until just before lesion induction. To ensure stabilization and standardization in testing while minimizing the human factor, polylactic acid bipolar tip fixtures and a vertical holder were individually crafted for each tested forceps using a 3-dimensional printer (Figure 2). The bipolar forceps were positioned with the assistance of a vertical holder, ensuring a 90-degree angle to the tissue, with only the tip of the bipolar forceps making contact. Lesions were made on the surface of each liver specimen with all bipolar forceps with a 35 Malis-unit power setting, 1-mm tip spacing, and 3-second activation time. These settings represent the most frequently used values and were determined by evaluating the settings used in other studies.[16,17,25]

Thermometry Measurement

To compare the tissue temperatures during each bipolar coagulation, additional 90 controlled coagulations were performed on ex vivo bovine liver samples (15 trials per forceps). Controlled coagulation was performed after the thermocouple needle probes were placed perpendicular to the tissue. During coagulation, a multichannel data logger (Extech SDL200; Extech Instruments) recorded temperature changes 2 mm deep in the tissue. Temperature changes were captured by the thermocouple probe (Figure 3).

Tissue Coagulation and Assessment

Tissues were allowed to reach equilibrium for 1 hour after coagulation before staining. Liver tissue was cut into 20-mm-thick slices around the coagulation site. A 2% solution of 2,3,5-triphenyl tetrazolium chloride (tetrazolium red) solution was poured onto the liver specimens, which

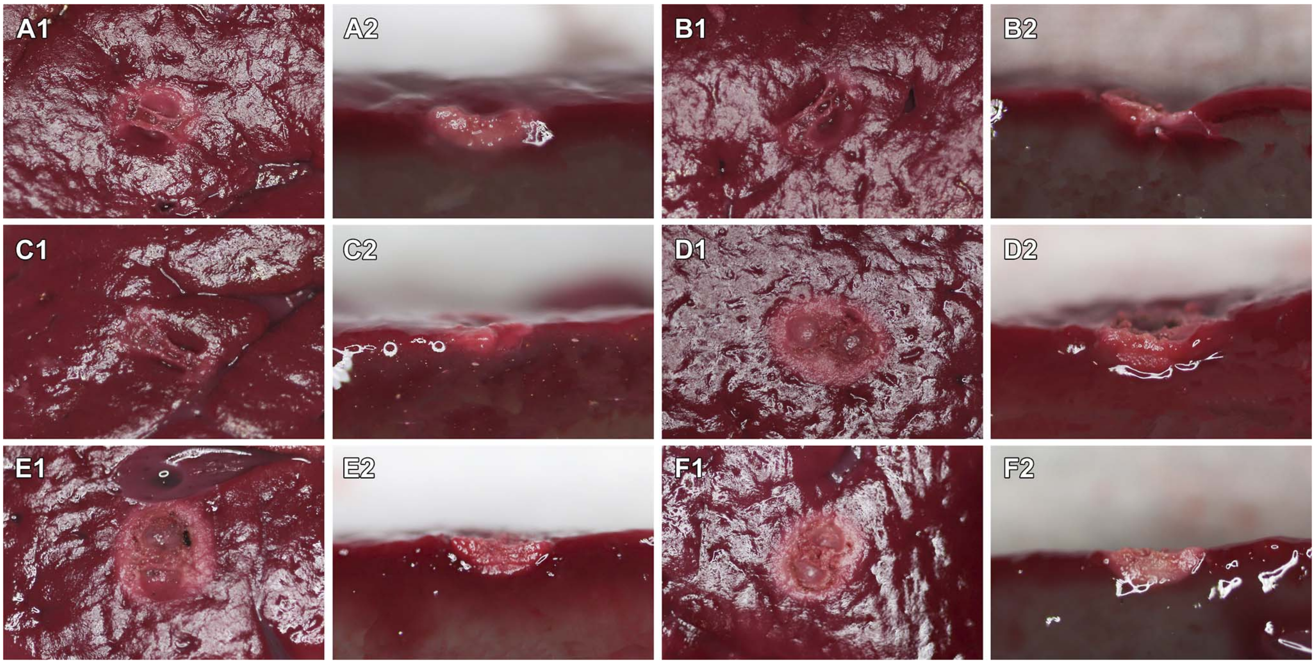

FIGURE 4. *Gross lesion images after staining with tetrazolium red.* **A**, *Aesculap ® non-stick: left, axial section; right, coronal section.* **B**, *Atlas Choice™: left, axial section; right, coronal section.* **C**, *ISOCOOL ®: left, axial section; right, coronal section.* **D**, *SilverGlide ®: left, axial section; right, coronal section.* **E**, *Spetzler™-Malis ®: left, axial section; right, coronal section.* **F**, *VersaTru ®: left, axial section; right, coronal section.*

were incubated at 37°C for 20 minutes in the dark. Tissue slices were immersed in a 2% aqueous solution of phosphate-buffered saline for 60 minutes at room temperature. Images of the gross lesions were taken after staining with tetrazolium red. The maximal depth of thermal injury was defined as the vertical line from the cortical surface to the point of deepest injury and measured manually with Image J (National Institute of

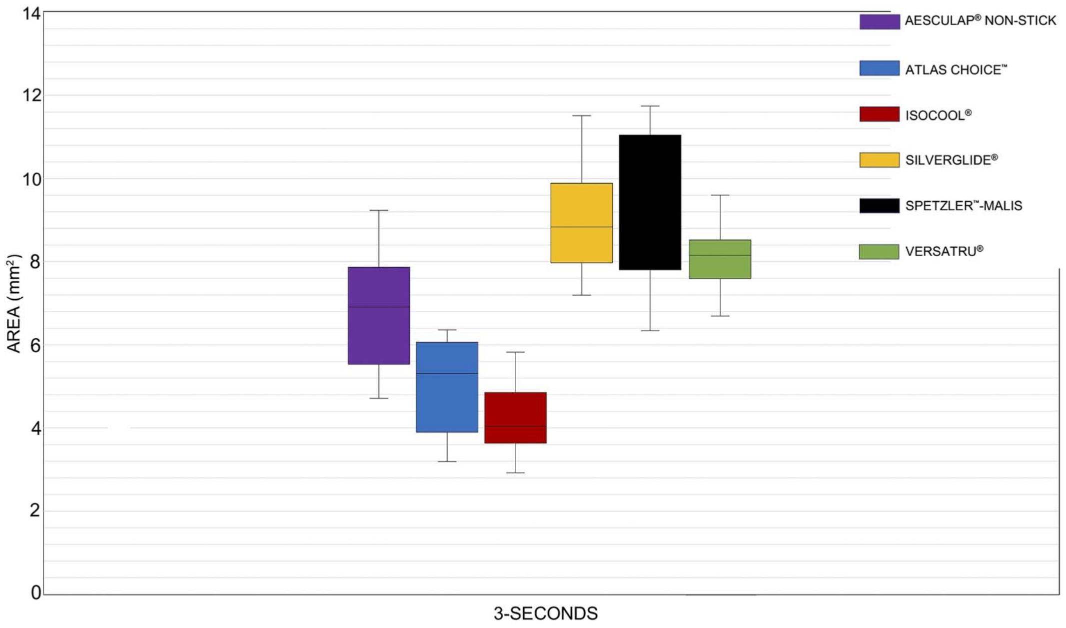

FIGURE 5. *This boxplot shows the measurements of the thermal damage area after a 3-second coagulation.*

TABLE 1. Thermal Injury Area Measurements and Comparisons of the Bipolar Forceps (Mean ± SD and P Values[a])

Bipolar forceps	Aesculap® non-stick	Atlas Choice™	ISOCOOL®	SilverGlide®	Spetzler™-Malis®	VersaTru®
Aesculap® non-stick		6.81 mm^2 ± 1.39	6.81 mm^2 ± 1.39	6.81 mm^2 ± 1.39	6.81 mm^2 ± 1.39	6.81 mm ± 1.39
		5.03 mm^2 ± 1.07	4.17 mm^2 ± 0.80	9.05 mm^2 ± 1.35	9.27 mm^2 ± 1.69	8.07 mm^2 ± 0.84
		$P < .001$	$P < .001$	$P < .001$	$P < .001$	$P = .002$
Atlas Choice™	5.03 mm^2 ± 1.07		5.03 mm^2 ± 1.07	5.03 mm^2 ± 1.07	5.03 mm^2 ± 1.07	5.03 mm^2 ± 1.07
	6.81 mm^2 ± 1.39		4.17 mm^2 ± 0.80	9.05 mm^2 ± 1.35	9.27 mm^2 ± 1.69	8.07 mm^2 ± 0.84
	$P < .001$		$P = .08$	$P < .001$	$P < .001$	$P < .001$
ISOCOOL®	4.17 mm ± 0.80	4.17 mm^2 ± 0.80		4.17 mm^2 ± 0.80	4.17 mm^2 ± 0.80	4.17 mm^2 ± 0.80
	6.81 mm ± 1.39	5.03 mm^2 ± 1.07		9.05 mm^2 ± 1.35	9.27 mm^2 ± 1.69	8.07 mm^2 ± 0.84
	$P < .001$	$P = .08$		$P < .001$	$P < .001$	$P < .001$
SilverGlide®	9.05 mm^2 ± 1.35	9.05 mm^2 ± 1.35	9.05 mm^2 ± 1.35		9.05 mm^2 ± 1.35	9.27 mm^2 ± 1.69
	6.81 mm^2 ± 1.39	5.03 mm^2 ± 1.07	4.17 mm^2 ± 0.80		9.27 mm^2 ± 1.69	8.07 mm^2 ± 0.84
	$P < .001$	$P < .001$	$P < .001$		$P < .98$	$P < .001$
Spetzler™-Malis®	9.27 mm^2 ± 1.69	9.27 mm^2 ± 1.69	9.27 mm^2 ± 1.69	9.27 mm^2 ± 1.69		9.05 mm^2 ± 1.35
	6.81 mm^2 ± 1.39	5.03 mm^2 ± 1.07	4.17 mm^2 ± 0.80	9.05 mm^2 ± 1.35		8.07 mm^2 ± 0.84
	$P < .001$	$P < .001$	$P < .001$	$P < .001$		$P < .03$
VersaTru®	8.07 mm^2 ± 0.84	8.07 mm^2 ± 0.84	8.07 mm^2 ± 0.84	8.07 mm^2 ± 0.84	8.07 mm^2 ± 0.84	
	6.81 mm^2 ± 1.39	5.03 mm^2 ± 1.07	4.17 mm^2 ± 0.80	9.27 mm^2 ± 1.69	9.05 mm^2 ± 1.35	
	$P < .001$	$P < .001$	$P < .001$	$P = .003$	$P < .03$	

[a] P values < .05 statistically significant level.

Health) in all tissue sections. Similarly, the maximal surface area of injury was traced manually and quantified with Image J.[26]

Statistical Analysis

Statistical analysis was performed using SPSS 22.0 software (IBM Corporation). The mean area and depth of injury were compared between groups using one-way analysis of variance, followed by a post hoc Tukey test for multiple-group comparisons. All results were presented as mean ± SD. The statistical significance criterion was established at $P < .05$.

RESULTS

Area of Thermal Injury

Multiple group comparisons with the post hoc Tukey test revealed that the injured area resulting from coagulation with ISOCOOL® and Atlas Choice™ bipolar forceps were not statistically significantly different from each other (ISOCOOL®: 4.17 ± 0.80 mm^2 vs Atlas Choice™: 5.03 ± 1.07 mm^2; $P = .08$). The areas of thermal injury caused by the ISOCOOL® and Atlas Choice™ forceps were statistically significantly less than those of the Aesculap® non-stick (Aesculap® non-stick: 6.81 ± 1.39 mm^2; $P < .001$), SilverGlide® (SilverGlide®: 9.05 ± 1.35 mm^2; $P < .001$), Spetzler™-Malis® (Spetzler™-Malis®: 9.27 ± 1.69 mm^2; $P < .001$), and VersaTru® (VersaTru®:8.07 ± 0.84 mm^2; $P < .001$). The areas of thermal injury caused by the SilverGlide® were measured as 9.05 ± 1.35 mm^2. The thermal damage area (Figure 4), measured following a 3-second coagulation, is illustrated in the box plot for each bipolar forceps (Figure 5). In pairwise group comparisons, a statistically significant difference was observed for thermal damage area measurements of other bipolar forceps (Table 1).

Depth of Thermal Injury

Multiple comparisons were made with the post hoc Tukey test to assess variations in thermal injury depth produced by the different forceps pairs. This analysis revealed no statistically significant difference in thermal injury depth between the ISOCOOL® and Atlas Choice™ bipolar forceps (ISOCOOL®: 0.7027 ± 0.117 mm, Atlas Choice™: 0.7020 ± 0.113 mm; $P = 1.0$). The depths of

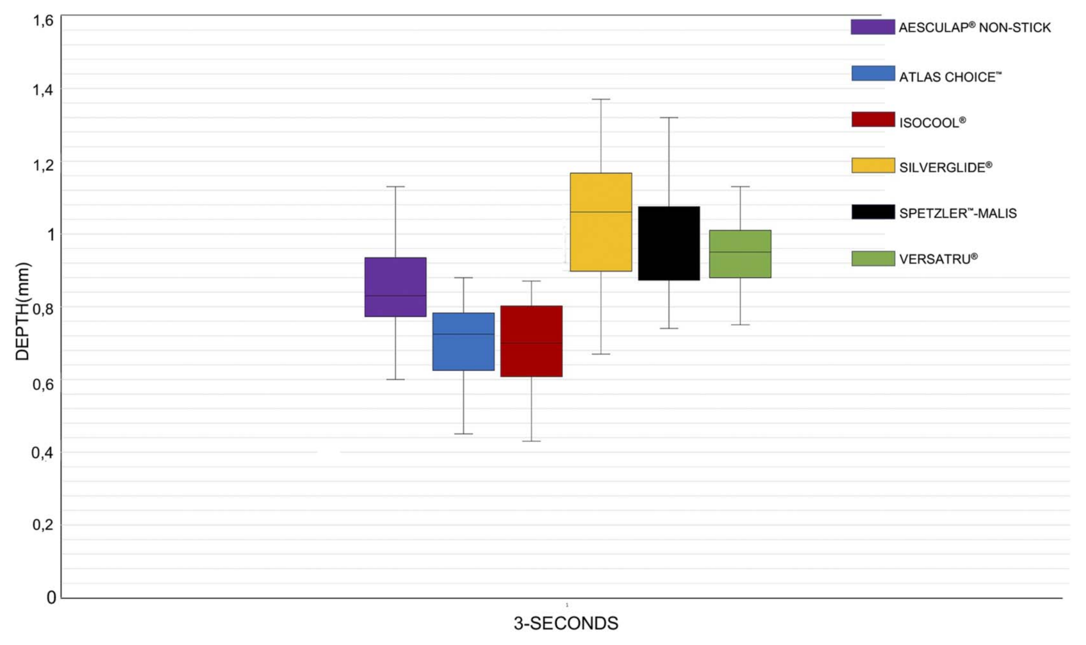

FIGURE 6. *This boxplot shows the measurements of thermal damage depth after a 3-second coagulation.*

thermal injury caused by ISOCOOL® and Atlas Choice™ bipolar forceps were statistically significantly less than that of the Aesculap® non-stick (Aesculap® non-stick: 0.85 ± 0.148 mm; $P = .001$), SilverGlide® (SilverGlide®: 1.03 ± 0.170 mm; $P < .001$), Spetzler™-Malis® (Spetzler™-Malis®: 0.97 ± 0.169 mm; $P < .001$), and VersaTru® (VersaTru®: 0.95 ± 0.111 mm; $P < .001$). The depth of thermal injury caused by Spetzler™-Malis® bipolar forceps was not statistically significantly different from that of the SilverGlide® forceps (Spetzler™-Malis®: 0.97 ± 0.169 mm, SilverGlide®: 1.03 ± 0.170 mm; $P = .54$) and VersaTru® (Spetzler™-Malis®: 0.97 ± 0.169 mm, VersaTru®: 0.95 ± 0.111 mm; $P = .98$) The analysis revealed no statistically significant difference in thermal injury depth between the SilverGlide® and VersaTru® bipolar forceps (SilverGlide®: 1.03 ± 0.170 mm, VersaTru®: 0.95 ± 0.111 mm; $P = .18$). The depths of thermal injury caused by the Aesculap® non-stick and VersaTru® bipolar forceps were not statistically significantly different from each other (Aesculap® non-stick: 0.85 ± 0.148 mm, VersaTru®: 0.95 ± 0.111 mm; $P = .08$). The thermal damage depth, measured following a 3-second coagulation, is illustrated in the box plot for each bipolar forceps (Figure 6). Multiple group comparisons revealed that the measurements of the depth of thermal damage caused by coagulation with other bipolar forceps were statistically significantly different from each other (Table 2).

Tissue Thermometry Results

Figure 7 illustrates the comparison of average temperatures (°C/s) during a 3-second coagulation period for the 6 forceps. Significant temperature changes were measured with the thermocouple probe positioned close to the tissue surface. For all bipolar forceps, average tissue temperatures reached 60°C within the targeted coagulation area. However, the ISOCOOL®, Atlas Choice™, and Aesculap® non-stick bipolar forceps exhibited a slower increase in temperature, maintaining tissue temperature approximately 20% to 25% lower compared with the Spetzler™-Malis® forceps.

DISCUSSION

Numerous advancements have emerged in bipolar cauterization technologies since their initial introduction by Greenwood in 1942.[4,6,7] While working in a physiology laboratory in 1956, Leonard Malis developed a bipolar coagulator that could coagulate fine blood vessels without damaging surrounding tissues in the animal brain. This device began to be widely used for blood vessels near vital tissues.[6,7,10,13] Yaşargil emphasized that bipolar forceps showed exceptional utility and played a crucial role in facilitating the much-needed breakthrough for the advancement of microsurgery. Using modern bipolar coagulation for more than just maintaining hemostasis, he showed that this technique can be applied to various other advantageous microsurgical techniques.[27] These include gentle dissection of neural structures and reshaping of aneurysm necks for precise clipping, among other valuable applications.[1,13]

Recent progress in manufacturing capabilities has enabled the production of a diverse array of forceps tip sizes and configurations. These developments aimed to enhance surgical precision,

TABLE 2. **Thermal Injury Depth Measurements and Comparisons of the Bipolar Forceps (Mean ± SD and P Values[a])**

Bipolar forceps	Aesculap® non-stick	Atlas Choice™	ISOCOOL®	SilverGlide®	Spetzler™-Malis®	VersaTru®
Aesculap® non-stick		0.85 mm ± 0.148	0.85 mm ± 0.148	0.85 mm ± 0.148	0.85 mm ± 0.148	0.85 mm ± 0.148
		0.7020 mm ± 0.113	0.7027 mm ± 0.117	1.03 mm ± 0.170	0.97 mm ± 0.169	0.95 mm ± 0.111
		$P < .001$	$P = .001$	$P < .001$	$P = .013$	$P = .087$
Atlas Choice™	0.7020 mm ± 0.113		0.7020 mm ± 0.113	0.7020 mm ± 0.113	0.7020 mm ± 0.113	0.7020 mm ± 0.113
	0.85 mm ± 0.148		0.7027 mm ± 0.117	1.03 mm ± 0.170	0.97 mm ± 0.169	0.95 mm ± 0.111
	$P < .001$		$P = 1.0$	$P < .001$	$P < .001$	$P < .001$
ISOCOOL®	0.7027 mm ± 0.117	0.7027 mm ± 0.117		0.7027 mm ± 0.117	0.7027 mm ± 0.117	0.7027 mm ± 0.117
	0.85 mm ± 0.148	0.7020 mm ± 0.113		1.03 mm ± 0.170	0.97 mm ± 0.169	0.95 mm ± 0.111
	$P = .001$	$P = 1.0$		$P < .001$	$P < .001$	$P < .001$
SilverGlide®	1.03 mm ± 0.170	1.03 mm ± 0.170	1.03 mm ± 0.170		1.03 mm ± 0.170	0.97 mm ± 0.169
	0.85 mm ± 0.148	0.7020 mm ± 0.113	0.7027 mm ± 0.117		0.97 mm ± 0.169	0.95 mm ± 0.111
	$P < .001$	$P < .001$	$P < .001$		$P = .54$	$P = .98$
Spetzler™-Malis®	0.97 mm ± 0.169	0.97 mm ± 0.169	0.97 mm ± 0.169	0.97 mm ± 0.169		1.03 mm ± 0.170
	0.85 mm ± 0.148	0.7020 mm ± 0.113	0.7027 mm ± 0.117	1.03 mm ± 0.170		0.95 mm ± 0.111
	$P = .013$	$P < .001$	$P < .001$	$P = .54$		$P = .18$
VersaTru®	0.95 mm ± 0.111	0.95 mm ± 0.111	0.95 mm ± 0.111	0.95 mm ± 0.111	0.95 mm ± 0.111	
	0.85 mm ± 0.148	0.7020 mm ± 0.113	0.7027 mm ± 0.117	0.97 mm ± 0.169	1.03 mm ± 0.170	
	$P = .087$	$P < .001$	$P < .001$	$P = .98$	$P = .18$	

[a] P values < .05 statistically significant level.

facilitate effective hemostasis, and minimize the occurrence of tissue adhesion to the instrument tips.[22,23]

Efficient bipolar coagulation is accomplished through the application of high-frequency electrical current, inducing the movement of water molecules. This rapid movement of water molecules produces heat, leading to desiccation and the efficient coagulation of hemorrhagic tissues.[17] Preventing charring and tissue adhesion has been the primary objective for bipolar coagulator manufacturers worldwide. In pursuit of these outcomes, they have investigated new techniques and various metallurgical compositions for the forceps. In 1972, King and Worpole[18] developed the continuous saline drip irrigator, which ensures a continuous flow of saline even when the bipolar coagulator is turned off. In 1975, Dujovny and his team developed an automatic irrigation system.[19] Around the same time, suction irrigation forceps were modified by Scarff,[20] but their use was complicated, and the irrigation was difficult to manage.

Various materials have been used to minimize adhesion and charring. Mikami and associates conducted a comparative analysis of forceps materials, including gold, titanium, and stainless steel, and observed markedly reduced tissue adherence in the case of gold-plated bipolar forceps.[3] Hsiao and colleagues[28] observed a significant reduction in the total injury area of rat brain tissues treated with stainless-steel electrodes coated with a titanium dioxide layer, as compared with untreated electrodes. Among other innovations, irrigation systems,[20,29,30] automatic thermo-control systems,[31] two-stage heating pattern generators,[32] and computer-controlled minimum impedance coagulation systems[33] have been introduced. Nonetheless, despite these developments, excessive tissue heating continues to present a challenge in modern clinical practice for most bipolar forceps.

Thermal dissipation has been defined as a significant factor in bipolar functionality, as observed with the use of the ISOCOOL® bipolar forceps, which use AHT through fluid-filled heat pipes to dissipate heat.[16,17,24] The heat pipe technology facilitates the continuous removal of excess heat from the bipolar tips, allowing more consistent coagulation temperatures. Within each forceps shaft is a vacuum-sealed tube containing a two-phase working fluid. Heat at the forceps tip is conveyed to the working fluid, causing vaporization and migration toward the proximal ends of

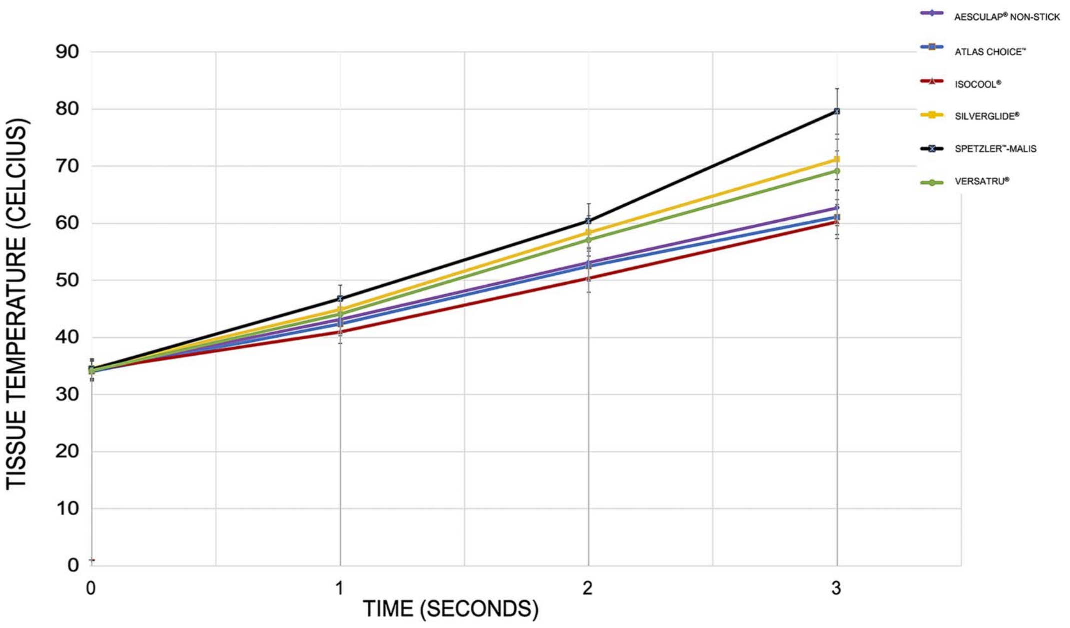

FIGURE 7. *Line graphs showing the 3-second temporal temperature profiles for the 6 different bipolar forceps.*

the bipolar shafts, where the fluid condenses within a wicking structure. The wicking structure facilitates the return of cooled and condensed working fluid to the distal end of the tip through capillary action.[17] ISOCOOL® bipolar forceps are available in several handle sizes (8.5, 9.5, and 10.5 inches) and tip sizes (0.25, 0.5, 1.0, and 2.0 mm).

The tips of the Atlas Choice™ bipolar forceps are made primarily from silver. These silver tips exhibit superior heat dissipation and nonstick properties because of high-conduction abilities of silver. Furthermore, since they enhance conductivity, they require less generator power for effective coagulation compared with silver-plated tips. Because the tips of these forceps are not separately disposable from their handles, the risk of misalignment of the tips is minimized.

Limitations

Our study has certain limitations. The bovine liver specimens were maintained in a temperature-controlled water bath before temperature measurement. After being extracted from the water bath, there was some heat loss, resulting in a failure to maintain the initial temperature. For each test, however, the initial temperature change between the devices was minimal. The technical feasibility of conducting analysis on ex vivo hepatic tissues is straightforward; however, the tissue temperatures measured in this study are specific to hepatic tissues and may not directly reflect that of other tissue types. Furthermore, ex vivo tissues do not account for the thermal effects associated with the perfusion that occurs in living tissues. The use of a bipolar generator, coagulation duration, power setting, the angle between the bipolar tip and tissue surface, the gap between forceps tips, and the contact between the bipolar tip and tissue surface, all controllable variables, were matched across groups to strengthen the study's outcome. In a study conducted by Elliot Lewis et al,[17] 2 different bipolar forceps were compared in vivo rat brain and ex vivo hepatic tissues. Consistent with findings in our study, AHT technology significantly reduced the width of thermal injury to in vivo rat brain and the area of thermal injury to ex vivo hepatic tissues.

Irrigation was not used during any coagulation procedure because of the potential of irrigation factors, such as the quantity and temperature of the irrigation fluid, to alter tissue temperature and, therefore, tissue damage.

CONCLUSION

In this study, we conducted a comparative analysis of the adjacent thermal injury profiles induced by 6 different bipolar forceps on ex vivo bovine liver tissues. The results indicate that ISOCOOL® and Atlas Choice™ bipolar forceps led to a smaller depth and area of thermal injury compared with the Aesculap® nonstick, SilverGlide®, Spetzler™-Malis®, and VersaTru® bipolar forceps.

In ex vivo bovine liver tissues, bipolar forceps with an AHT or enhanced heat dissipation at the tips method limited excessive thermal spread and reduced the size of adjacent thermal damage compared with conventional bipolar forceps. This technology may be particularly valuable in ensuring effective and safe coagulation in critical vascular and neural tissues. The improvement and enhancement of the quality of bipolar forceps are critically important for the future of microneurosurgery.

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Disclosures

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REFERENCES

1. Bulsara KR, Sukhla S, Nimjee SM. History of bipolar coagulation. *Neurosurg Rev.* 2006;29(2):93-96.
2. Vällfors B, Erlandson BE, Wieck BO, Hansson HA, Svensson J. Coagulation in neurosurgery. *Acta Neurochir (Wien).* 1980;55(1-2):29-34.
3. Mikami T, Takahashi A, Hashi K, Gasa S, Houkin K. Performance of bipolar forceps during coagulation and its dependence on the tip material: a quantitative experimental assay. Technical note. *J Neurosurg.* 2004;100(1):133-138.
4. Greenwood J. Two point coagulation: a new principle and instrument for applying coagulation current in neurosurgery. *Am J Surg.* 1940;50(2):267-270.
5. Dujovny M, Dujovny N, Gundamraj NR, Misra M. Bipolar coagulation in neurosurgery. *Surg Neurol.* 1998;49(3):328-332.
6. Malis LI. *Acoustic Neuroma*. Elsevier; 1998.
7. Donaghy RMP, Yaşargil MG. Micro-vascular surgery: report of first conference, October 6-7, 1966, Mary Fletcher Hospital. Burlington, Vermont: CV Mosby Company; 1967.
8. Malis LI, Apuzzo MLJ. Electrosurgery and bipolar technology. *Neurosurgery.* 2006; 58(1 Suppl):ONS1-ONS12.
9. Malis LI. Electrosurgery. Technical note. *J Neurosurg.* 1996;85(5):970-975.
10. Malis JL. Technical contributions of Leonard I. Malis. *Mt Sinai J Med.* 1997;64(3): 172-181.
11. Yaşargil MG. A legacy of microneurosurgery: memoirs, lessons, and axioms. *Neurosurgery.* 1999;45(5):1025-1092.
12. Choque-Velasquez J, Colasanti R, Jahromi BR, Rafei A, Sharafeddin F, Hernesniemi J. Short-burst bipolar coagulation for repairing partially damaged brain arteries preserving their flow: technical note. *World Neurosurg.* 2016;93: 324-329.
13. Yasargil MG. *Microsurgery: Applied to Neurosurgery*. Georg Thieme Verlag; 1969; 10(122):4-10,41-45, 122, 140-141.
14. Yaşargil MG. Personal considerations on the history of microneurosurgery. *J Neurosurg.* 2010;112(6):1163-1175.
15. Yaşargil MG, Abernathey CD. *Microneurosurgery*, Vol IV B. Thieme; 1996.
16. Elliott-Lewis EW, Benzel EC. Thermal comparison of novel bipolar forceps in bovine liver. *Neurosurgery.* 2010;67(1):160-165.
17. Elliott-Lewis EW, Mason AM, Barrow DL. Evaluation of a new bipolar coagulation forceps in a thermal damage assessment. *Neurosurgery.* 2009;65(6):1182-1187.
18. King TT, Worpole R. Self-irrigating bipolar diathermy forceps. Technical note. *J Neurosurg.* 1972;37(2):246-247.
19. Dujovny M, Vas R, Osgood CP, Maroon JC, Janetta PJ. Automatically irrigated bipolar forceps. Technical note. *J Neurosurg.* 1975;43(4):502-503.
20. Scarff TB. A new bipolar suction-cautery forceps for micro-neurosurgical use. *Surg Neurol.* 1974;2(3):213.
21. Jacques S, Bullara LA, Pudenz RH. Microvascular bipolar coagulator. Technical note. *J Neurosurg.* 1976;44(4):523-524.
22. Mikami T, Minamida Y, Koyanagi I, Houkin K. Novel bipolar forceps with protein repellence using gold-polytetrafluoroethylene composite film. *Neurosurgery.* 2007; 60(2 Suppl 1):S157–ONS161.
23. Samii A, Dujovny M. Kirwan "non-stick" bipolar forceps. *Surg Neurol.* 1996;45(3): 297-298.
24. Elliott-Lewis EW, Jolette J, Ramos J, Benzel EC. Thermal damage assessment of novel bipolar forceps in a sheep model of spinal surgery. *Neurosurgery.* 2010;67(1): 166-172.
25. Roy AK, Turan N, Wangmo P, Nkrumah L, Neill SG, Pradilla G. Comparatıve assessment of thermal ınjury ınduced by bıpolar electrocautery systems ın a porcıne model. *Surg Neurol Int.* 2021;12:146.
26. Schneider CA. NIH Image to ImageJ: 25 years of image analysis. *Nat Methods.* 2012;9(7):671-675.
27. Yasargil MG. The advent of microsurgery. *Mt Sinai J Med.* 1997;64(3):164-165.
28. Hsiao WT, Kung CM, Chu JS, Ou KL, Peng PW. Research of electrosurgical ablation with antiadhesive functionalization on thermal and histopathological effects of brain tissues in vivo. *Biomed Res Int.* 2014;2014:182657.
29. Dujovny M, Vas R, Osgood CP. Bipolar jeweler's forceps with automatic irrigation, for coagulation in microsurgery. *Plast Reconstr Surg.* 1975;56(5):585-587.
30. Sano H, Kato Y, Zhou J, et al. New jet irrigation bipolar system. *Neurosurgery.* 1996;38(6):1251-1253.
31. Sugita K, Tsugane R. Bipolar coagulator with automatic thermocontrol. Technical note. *J Neurosurg.* 1974;41(6):777-779.
32. Casotto A, Castrioto C, Orvieto P. An advanced system for electrocoagulation in neurosurgery. *J Neurosurg Sci.* 1988;32(2):61-63.
33. Bergdahl B, Vallfors B. Studies on coagulation and the development of an automatic computerized bipolar coagulator. Technical note. *J Neurosurg.* 1991;75(1):148-151.

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