

# A Review of Capacitive Return Electrodes in Electrosurgery

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**Abstract:** Background: Monopolar electrosurgery, one of the most widely used techniques in surgery, requires two electrodes: a working electrode and a return electrode. Commonly, adhesive or “sticky” pads that attach directly to the patient are used as return electrodes. Acting as electrolytic conductors, adhesive pads are highly effective, but require some effort to apply and remove, and if improperly placed or partially detached may lead to high electrical current density and the potential for pad site burns. Alternatively, a capacitive return electrode, such as the Mega Soft pad, may be used that works on the same principle as a two-plate capacitor. Objective: This article details the technology underlying capacitive electrodes, reviews the scientific literature to-date, and provides recommendations on how to best use the Mega Soft pad. Results: No direct contact is required between the pad and patient, and the return electrode is designed so that current density is limited regardless of pad placement, reducing the risk of pad site burn. Although the technology is now mature, having been in the field for over 20 years, best practices for optimal performance from capacitive return electrodes are still not widespread, and misunderstandings persist regarding use of capacitive electrodes with contact monitoring systems and implantable electronic devices. Conclusion: With proper training, capacitive return electrodes may be substituted for conventional adhesive pads with the benefits of easier application and reduced risk of pad site burns.

**Keywords:** Monopolar Electrosurgery, Adhesive Return Electrode, Capacitive Return Electrode, Pad Site Burns

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## 1. Introduction

Over 20 years ago, Megadyne introduced the Mega Soft patient return electrode for use in monopolar electrosurgery. The Mega Soft pad is radically different from conventional adhesive electrode pads. Working via capacitive coupling, similar to a two-plate capacitor, the pad does not require direct contact with the patient’s skin, eliminating the need for skin preparation, such as shaving, and the removal of an adhesive pad after surgery. The unique design of the Mega Soft pad limits the current density to a low level, substantially decreasing the risk of a pad site burn, due to a misplaced adhesive pad electrode.

Despite its growing use, training on the proper use of the Mega Soft pad is lagging, leading to potentially suboptimal use. This review article explains the technology behind the Mega Soft pad, gives a systematized survey of the scientific literature concerning pad use, and provides instructions for

optimum electrosurgery effect and safety.

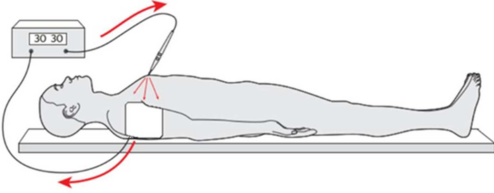
## 2. Technical Background

Monopolar electrosurgery involves two electrodes; a working electrode that transmits a high density current over a small area, and a return electrode that collects the electricity over a much larger area with a low current density. The high current density at the working electrode produces precise tissue effects, such as cutting and coagulation. The low current density at the return electrode provides minimal temperature increase and essentially no permanent tissue effect.

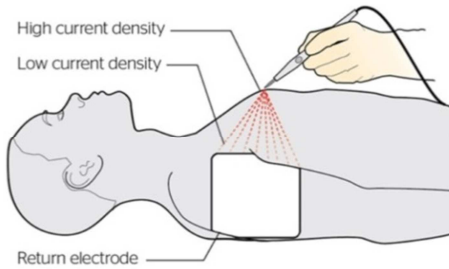
Adhesive return electrodes are designed with a large surface area to lower the current density (Figures 1, 2). The current in these electrodes is carried electrolytically via ions distributed in a gel. If the surface area of the electrode is accidentally decreased, the electrolytic gel may continue to conduct the same amount of current, but at a much higher current density.

This increase in current density will lead to an increase in tissue temperature and may result in what is termed a pad-site burn. There are methods of avoiding accidental decreases in contact surface area, such as Contact Quality Monitoring (CQM), but these techniques may also be bypassed.

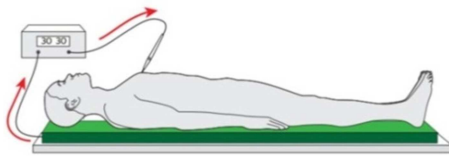
The Mega Soft return electrode, acting essentially as a two-plate capacitor, uses capacitive conduction, a non-contact method of charge transfer instead of electrolytic conduction (Figures 3, 4). The design of the Mega Soft pad inherently limits the current density which in turn limits the potential temperature increase at the return electrode decreasing the possibility of a pad site burn (Figure 5). Current industrial standards [1] specify that the maximum patient surface tissue temperature adjacent to an return electrode should not rise more than 6°C. Because of its large size and limited current density, the Mega Soft pad stays well within this limit regardless of electrosurgical generator settings [2-5].



**Figure 1.** Diagram of electrosurgery using an adhesive return electrode.



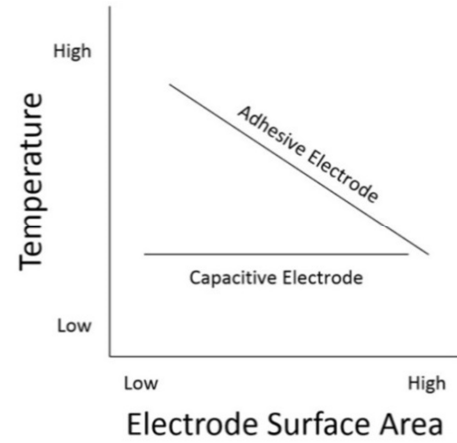
**Figure 2.** Close-up of electrosurgery showing high current density at the working electrode, and low current density at the return electrode.



**Figure 3.** Electrosurgery with a full-body capacitive electrode.



**Figure 4.** The Megadyne Mega Soft Universal Dual Plus Patient Return Electrode Pad.



**Figure 5.** Comparison of potential temperature increase for capacitive and adhesive electrodes as a function of surface area coverage.

To accomplish this limitation in current density, Mega Soft can be thought of as a large number of capacitive elements connected in parallel under the surface of the pad. Through any particular capacitor only a small current can flow, but when a large area of the surface is covered by the patient, a proportionally larger current is able to pass. If the patient moves so that they do not substantially cover the pad, then less current will flow through the working electrode, and hence there will be reduced current flow into the Mega Soft reducing the risk of a pad-site burn.

Typical currents used during electrosurgery are on the order of 500-700 mA, and a safe current density [1] is considered to be less than 100 mA/cm<sup>2</sup>. Assuming an upper limit for the current of 1000 mA, an electrosurgical return electrode must have a minimum size of:

$$Area \geq \frac{1000 \text{ mA}}{100 \text{ mA/cm}^2} = 10 \text{ cm}^2$$

In this simple model, if the area of a conventional return electrode decreases substantially below 10 cm<sup>2</sup>, then there is a chance of a pad-site burn. Additionally, current concentration along the edge of an adhesive pad may increase current density by roughly a factor of three. On the other hand, with Mega Soft the current density does not increase with a decrease in area or along the edges, thus even with a smaller area of coverage, the risk of a pad site burn is low.

The current flow through a capacitor depends upon the capacitive reactance, given as:

$$X_c = \frac{1}{2\pi f C}$$

where  $f$  is the frequency of the alternating current (typically 300 kHz to 1 MHz), and  $C$  is the capacitance. The capacitance of a parallel plate capacitor is given by:

$$C = \frac{k\epsilon_0 A}{t}$$

where  $k$  is the dielectric constant of the material separating

the plates,  $\epsilon_0$  is the electrical permittivity of air,  $A$  is the area of the plates, and  $t$  is the separation between the plates. By careful selection of the plate separation and area of the capacitor, the capacitive reactance can be controlled so that current density never goes above 100 mA/cm<sup>2</sup>. This occurs when the bulk resistivity of the pad is approximately 100,000  $\Omega$ .cm.

### 3. Product Benefits

The Mega Soft family of pads are non-contact capacitive return electrodes and provide patient comfort using a viscoelastic polymer as an integral part of the pad, especially important for surgeries of relatively long duration. Megadyne first introduced a capacitive return electrode without gel cushioning in 1999 with the Mega 2000 followed by an 8 kg pad designed with cushioning for patients greater than 11 kg and offered a non-contact electrode in a thick cushion. The Mega Soft pad was introduced in 2002 and offered the same features. The Pediatric version of 2009 was designed for children weighing 0.4 – 23 kg. After the purchase of Megadyne by Ethicon, Inc., the latest versions of Mega Soft, the Universal and Universal Plus, both sought to make the pad less bulky and easier to maneuver. The Universal weighed only 2 kg and could be used on patients weighing 0.4 kg and up. Since much of the cushioning was removed, the Universal was most suitable for short procedures, or when used with other cushioning underneath the pad. The Universal Plus, introduced in 2019, weighs just under 4 kg and accommodates the same patient weight range. Both the Universal and Universal Plus are faster at transmitting heat from a heating device located underneath the pad.

Since electrosurgical devices are used in approximately 80% of surgical procedures [6, 7], cost considerations for this category are important to the economics of hospital systems. The cost of ownership was calculated for both reusable capacitive return electrodes, such as the Mega Soft Reusable Patient Return Electrode and disposable adhesive return electrodes (Table 1). The adhesive electrode cost includes the price of each disposable electrode (conservatively assumed as one unit per procedure), whereas the cost of Mega Soft includes the product acquisition cost of each reusable pad, assuming that one unit is adopted per operating room (OR). This calculation also assumes that a typical OR hosts four surgical procedures per day where an electrosurgery device is utilized, with 260 working days over the course of a year. [8] Over Mega Soft's expected life of two years, the total cost of ownership per Mega Soft Reusable Patient Return Electrode unit is \$2,482 and for adhesive electrodes it is \$6,614.40 over the same time period. This equates to a \$4,132.4 (62%) lower cost for Mega Soft.

Beyond product acquisition costs, Mega Soft reduces the need for disposal of electrodes after each procedure, which in turn reduces excess medical waste and the consequent medical waste disposal costs. The reusable nature of Mega Soft, relative to the single-use nature of adhesive electrodes, could also be of interest to hospital stakeholders from an

environmental sustainability perspective.

**Table 1.** Total cost of ownership for the Mega Soft Reusable Patient Return Electrode and disposable adhesive return electrodes.

Parameter	Mega Soft	Adhesive Electrode
Device cost (per unit)	\$2,482	\$3.18
Device life cycle	2 years	1 procedure
Number of procedures per OR over 2 years (4 procedures/day X 260 days/year X 2 years)	2,080	
Cost of ownership over 2 years	\$2,482	\$6,614.40

### 4. Literature Review

We performed electronic searches of Medline and Google Scholar for articles in English published from January 1999 through October 2020 on “Mega Soft” or “capacitive return electrode” and related terms. Reference lists were manually searched to identify any pertinent articles that had been missed. Overall, eight articles describing the use of Mega Soft were identified and selected to be narratively summarized below.

### 5. Use with Burn Patients

It is often difficult to find suitable sites for traditional electrode pads on patients with extensive skin burns due to the large area of the pad or the need to place the electrode within the operative site. Sheridan et al. [9] and Liodaki et al. [3] reported on case series of burn patients for which the Mega 2000 Patient Return Electrode System was used while undergoing electrosurgery. The authors reported that there were no cases of cutaneous device related burns or malfunction. The authors also noted that the Mega Soft pad allowed for a reduction in operation time as two operating teams could simultaneously work on the patient. In addition, when intraoperative repositioning of the patient was required, the repositioning of an adhesive electrode pad was not required. Finally, the authors found that there was no difficulty of placing return electrodes in the vicinity of a large area burn, as this pad is simply laid beneath the patient. Although the pad had a higher electrical resistance when compared to traditional adhesive pads, the large surface area of the pad more than compensated, resulting in reliable grounding.

### 6. Use in Patients with Implantable Devices

Patients with cardiac implanted electronic devices (CIED) are at risk of experiencing electromagnetic interference (EMI) when monopolar electrosurgery is used in a surgical procedure.[10] EMI events can be serious and may lead to patient injury. Rozner et al. [11] presented a case series of 3 patients with implantable cardioverter-defibrillator (ICDs) that were treated with electrosurgery, but not per the current guidelines as described by the American Society of

Anesthesiologists (ASA) or Heart Rhythm Society (HRS). They described a single case where the operators utilized a Mega Soft return electrode with short burst monopolar electrosurgery to mitigate EMI risk in an ICD pocket. No adverse events were reported. Gifford *et al.* [12] evaluated 331 patients with transvenous CIEDs. Rates of EMI caused by electrosurgery were compared for various surgical locations. An unspecified number of patients utilized the Megadyne whole body universal return pad when this was characterized as part of routine care for the procedure. Incidence of EMI was not reported as related to the type of return electrode, and there were no inappropriate therapies or device resets. Schulman *et al.* [13] evaluated the use of electrosurgery in 144 patients with ICDs. The Mega Soft return electrode was used in 34 subjects undergoing cardiac surgery. The level of EMI was considered to be high in the cardiac subjects, however the authors were unable to determine if use of the pad contributed to the EMI since they had no comparative control of a conventional adhesive electrode. Lefevre *et al.* [14] observed ICD discharges when using electrosurgery during bladder surgery with the Mega Soft pad under the patient's torso. Tully *et al.* [15] also observed ICD discharges when using electrosurgery during sacral debridement with the Mega Soft pad under the patient's torso. In these cases, the ICD had not been reprogrammed or disabled with a magnet prior to the procedure. As with adhesive electrodes, the Mega Soft pad should not be placed directly under the heart when a patient has an activated ICD.

## 7. Bypassing the Safety Mechanism of a Capacitive Pad

Park *et al.* [16] managed to overcome the inherent safety profile of the Mega Soft pad by accidentally creating an alternative pathway with a stainless steel tube tree. This metal structure conducted current via capacitance over a large area of the pad. The patient, who was only partially extended over the pad, happened to touch a small part of the tube and the concentrated current caused a minor burn. For maximum efficacy and safety, the patient should cover as much of the pad as possible, and no large metal objects should be placed between the pad and patient.

## 8. Tips on Using the Mega Soft Pad

The perioperative registered nurse engages critical thinking skills routinely when preparing for the safe use of electrosurgery and minimizing the risk of patient injury. Considerations include proper pad site selection and preparation, appropriate pad placement, positioning of the patient, and the surgeon's power settings.

When changing from a traditional electrosurgical patient return electrode (adhesive pad) to a capacitive patient return electrode (Mega Soft), the traditional knowledge base such as pad placement, positioning, and power settings can bring up

new questions as these may differ. Since traditional "sticky" pads require direct skin contact on a well vascularized, muscular area free from hair, metal, implants, scar tissue, and fluids, the question of placing the patient that may have some or all of these conditions on the pad may concern members of the healthcare team. The Mega Soft patient return electrode does not require direct skin contact because it acts as a capacitor, and does not elicit the same concern with the patient skin factors listed above.

Excessive amounts of linens or other materials should not be placed between the patient and the pad. The use of excessive material between the patient and the electrode assembly may result in a diminished electrosurgical effect. A sheet and draw sheet may be placed over the Mega Soft pad. If a sheet is used, it should fit loosely over the electrode and be unstarched and free of wrinkles or folds.

A question that is frequently asked is where to place positioning pads, warming blankets and other items, ~~that~~ as Mega Soft is different than a sticky pad due to its larger size. If the item in question can go underneath the Mega Soft pad, that is the best option. Fluid filled warming pads, bean bag positioners, gel rolls, and frames should go beneath the Mega Soft or staggered to allow adequate contact of the patient to the pads. Mega Soft may be pre-warmed in a blanket warming cabinet but is not intended to be used in place of a warming device.

If, during the procedure, there is low power output or failure of the electrosurgical equipment to function correctly at normal settings, this may indicate excessive materials between the patient and Mega Soft. Customers should not increase power output before checking for obvious defects or misapplication. It is always important to maximize patient contact and minimize materials between the pad and the patient.

Traditional adhesive patient return electrodes require generators with Contact Quality Monitoring (CQM) used in combination with split-plate monitoring pads to help prevent patient burns during electrosurgical procedures. CQM pads are designed to provide feedback to the generator notifying it of poor contact quality. Once this feedback is received, the generator will alarm and will not allow the user to activate when it determines an unsafe condition.

Because of its unique design, Mega Soft does not require CQM. When a Mega Soft pad is connected to electrosurgical generators with CQM, the light on the generator will either display green or turn off completely. This is normal. A CQM generator alarm will not sound if the patient is not in contact with the Mega Soft pad. The current limiting technology built into the Mega Soft is designed to help prevent burns to the patient and occurs independent of traditional CQM systems found in isolated generators.

As with any electrosurgical device, power settings and surgical effects may differ from previous experiences and care should be taken. Always use the lowest possible power settings to achieve the desired surgical effect and refer to the generator manufacturer's operating instructions for proper usage of the electrosurgical equipment.

The materials in the patient return electrodes and accessories that have contact with human tissue and/or body fluids are well known in the medical device industry and are considered suitable for non-sterile, non-implanted patient return electrode devices. The thin, flexible urethane sheets used in Mega Soft directly transfer the shear forces encountered at the patient's skin/pad interface to a viscoelastic polymer.

The pad can be cleaned and disinfected with ordinary, commercially-available agents, such as solutions of quats. After cleaning, the pad should be rinsed with water and allowed to air dry before storage. Disinfectant containing more than 70% alcohol should not be used to clean Mega Soft, as it may cause hardening of the outer skin.

## 9. Conclusions

While there are situations where an adhesive return electrode may be more practical, the majority of electrosurgery procedures can be safely and effectively performed with a Mega Soft return electrode. A capacitive pad offers many advantages over traditional sticky electrodes, such as ease of placement, not requiring any special skin preparation, and little concern of pad site burns arising from misplacement.

Since the Mega Soft pad is reusable, substantial cost savings may be had over its lifetime of use. Savings accrue both from reduction in purchase of disposable electrodes, and from a substantial lowering of the cost of biomedical waste disposal.

Use of the Mega Soft pad is ultimately easier than using a sticky pad, however, there is a learning curve for those new to the technology. The recommendations contained herein were provided to aid in the transition from conventional return electrodes to modern capacitive electrodes and bring the benefits of the Mega Soft pad to both patients and staff.

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