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# Advances in the Design of a Curved Cutter Stapler for Colorectal Surgical Procedures

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## Abstract

**Background:** In colorectal procedures, including Low Anterior Resection (LAR), surgeons have found it beneficial to use a stapler designed to provide access in the deep pelvis such as the CONTOUR® Curved Cutter Stapler (CCS). A new version of this stapler, the ECHELON CONTOUR® Curved Cutter Stapler (ECCS) has been developed, featuring Gripping Surface Technology (GST) and Three-Dimensional (3D) staples. This study was undertaken to evaluate the ECCS in comparison to the previous version and another commercially-available stapler.

**Methods:** ECCS was compared to CCS for post-compression tissue trauma, both visually and via histological analysis, and post-stapling tissue healing response at 7- and 21-days post-surgery. ECCS was compared to the ENDO GIA Stapler (GIA) for leak onset pressure along the staple line.

**Results:** ECCS exhibited significantly less gross visible tissue trauma following compression than the predicate device ($p<0.001$). Histological examination indicated similar tissue trauma and tissue healing response for ECCS and CCS. In leak onset pressure testing, ECCS provided a 30.8% higher mean pressure than GIA ($p=0.002$), and a 55% lower leak rate at 30 mmHg ($p=0.011$).

**Conclusion:** To gain the benefits of hybrid laparoscopic colorectal techniques, the narrow head design of the CCS is particularly useful in accessing the deep pelvis. The new ECCS incorporates GST for enhanced tissue handling without any negative effect on tissue trauma or healing response. Additionally, ECCS uses 3D stapling technology which provides significantly stronger sealing. Together these technical advances make ECHELON CONTOUR® Curved Cutter Stapler the new standard in colorectal procedures.

**Keywords: Curved cutter stapler; Contour; Colorectal; Echelon; Low rectum; Pelvic access; Low anterior resection**

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## Introduction

Surgical staplers have been successfully used for over a century and during the intervening interval, the technology has progressed substantially [1]. The CONTOUR® Curved Cutter Stapler, a device which both cuts and staples, has been widely utilized in the past decade initially in open and more recently in hybrid laparoscopic colon and rectal surgical procedures [2-6]. The CONTOUR® Curved Cutter Stapler is a 4-row stapler designed with a small curved head for deep pelvic access. It is specifically useful in the narrow male pelvis where technical challenges exist associated with transecting the rectum while obtaining sufficient margins in decreased working space, including during Low Anterior Resection (LAR) [7]. In addition to its unique curved head, the stapler has a tissue retaining pin, which may be used to prevent slippage of the tissue from the jaws of the device. The knife extends to the retaining pin and the staple line extends beyond the pin, supporting multiple firings with a reloadable cartridge when needed to complete a single transection.

Even with past technical advances, sub-optimal tissue handling may produce inadvertent tissue injury leading to diminished perfusion, hindered healing and increased risk of Anastomotic Leaks (AL) [8] which is a dreaded and potentially deadly complication. AL is associated with peritonitis, sepsis, anastomotic dehiscence, abscess, fecal incontinence, reoperation, increased length of stay, and death [9-12]. Incidence rates vary from 0% to 36% in low anterior resection with clinically significant AL described between 10% to 14% [9,13].

Building upon the technology of the CONTOUR® Curved Cutter Stapler device, a next generation device, the ECHELON CONTOUR™ Curved Cutter Stapler, has been developed which introduces

**Figure 1:** Newly designed ECHELON CONTOUR™ Curved Cutter Stapler incorporating innovative proprietary GST and 3D stapling.

**Figure 2:** (Left) depicts Gripping Surface Technology ridges; (Right) illustrates 3D Stapling offset staple legs post-closure.

two new technologies, Gripping Surface Technology (GST) and 3D stapling, while maintaining all the functionality of the previous device (Figure 1). The newly incorporated GST utilizes a proprietary ridged surface which selectively compresses tissue based upon its proximity to the staple pocket in order to reduce overall compression forces without reducing sealing effectiveness to minimize tissue damage, decrease tissue slippage and reduce the risk of staple line leakage. Off-set closure of staple legs (crossing staple legs) is the basis for the 3D Stapling technology which minimizes stress points throughout the staple line while providing more evenly distributed compression (Figures 2).

The purpose of this study was to compare the new Echelon Contour Curved Cutter Stapler with the previous version in terms of staple line integrity, staple line leakage, tissue trauma and tissue healing. Benchtop and preclinical testing were performed in order to evaluate the benefits of the new device for all clinically relevant measures.

## Methods

### Test and control devices

Testing was performed to assess the predicate CONTOUR® Curved Cutter Stapler (CCS) and Green Staple Reload (CS40G/CR40G, Ethicon Inc., Cincinnati, OH) compared to the new ECHELON CONTOUR™ Curved Cutter Stapler (ECCS) and Green Staple Reload (GCS40G/GCR40G, Ethicon Inc., Cincinnati, OH). Comparative leak testing was performed comparing the new ECHELON device versus the market competitor Endo GIA™ Ultra Universal Stapler with Tri-Staple™ 2.0 Radial Intelligent Reload (EGIAUSTND/SIGRADMT, Medtronic, Minneapolis, MN).

### Visual and histological evaluations relative to tissue trauma

Benchtop studies were performed utilizing porcine colon tissue comparing the CCS device with the ECCS device. Based upon internal testing, harvested tissue was measured to a thickness of 3.60 ± 0.15 mm to mimic human colon tissue thickness of 80th to 90th percentile [14]. The tissue was then marked noting proximal and distal sides.

***Ex vivo* visual compression-related tissue trauma testing:** To

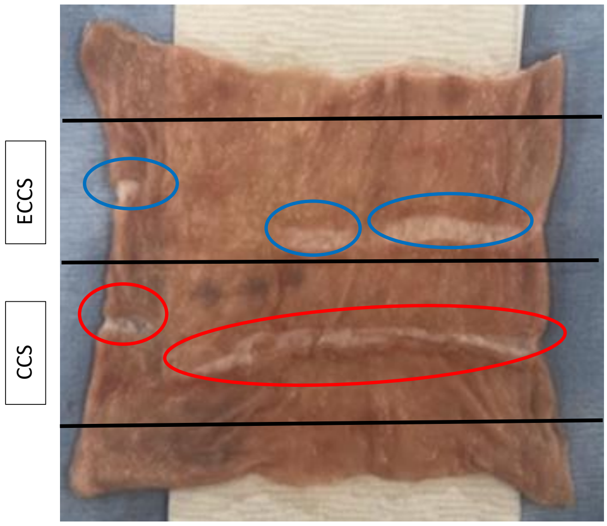


**Figure 3:** Example of tissue sample after paired clamping. Blanched damaged regions circled.

evaluate compression-associated tissue damage, paired applications were employed to allow exposure by both devices to the same test specimen to minimize variation in tissue properties. ECCS or CCS devices were closed transversely on the tissue using the closure trigger to provide localized compression. After approximately 15 sec, devices were opened and released from the tissue. The procedures were repeated on an adjacent area of the colon tissue using the alternative ECCS/CCS device. Tissue was prepared for assessment by opening the colon segment and gently stretching the tissue to expose the mucosal layer. Tissue damage was visually assessed by observing blanched areas where mucosa had been compressed (Figure 3). Tissue trauma was defined as percentage length of tissue to total length (colon circumference) with apparent mucosal damage. A two-sample t-test was performed to assess difference between the two devices.

***Ex vivo* histological compression-related tissue trauma testing:** Additional trauma testing was performed on explanted porcine colon samples post device closure (n=3 CCS, n=3 ECCS) and was characterized via histological examination. A single device was used for each sample in order to maintain integrity of sample. ECCS and CCS devices were applied transversely on tissue and closed without firing staples. Post device release, the colon was opened to expose the lumen and evaluate tissue damage. The total length of tissue damage at the site of device application and the sum of length of tissue damage was measured *via* examination of the mucosal aspect. Following testing, the site of device application was marked with tissues ink; samples attached to a laminate to prevent tissues from curling and stored in 10% Neutral Buffered Formalin (NBF) for histological analysis. Following fixation, specimens with obvious damage as well as sections from areas without apparent damage were trimmed and submitted for histology processing. Samples were paraffin embedded, sectioned, mounted on slides and stained with Hematoxylin and Eosin (H&E). Each slide contained two tissue sections: the section exhibiting the most damage was selected for grading. Illustrative histopathology images were captured with an Olympus DP73 microscope camera (CellSens Standard imaging software) attached to an Olympus BX46 brightfield microscope (Olympus, Tokyo, Japan).

### *In vivo* survival study - tissue healing response

Study protocol and procedures were reviewed and approved by the Institutional Animal Care and Use Committee, and GLP Regulations, 21 CRF, Part 58 were followed. Female pigs (n=18) underwent end-to-end circular colonic anastomoses at two sites following colon transection, proximal and distal on the descending colon. CCS and ECCS devices were used to create the distal linear staple lines. Following application of the circular stapler (Ethicon Curved Open Circular Stapler (CDH29A), Ethicon Inc., Cincinnati, OH) to create the anastomosis, a small portion of the linear staple line remained at the intersection of and adjacent to the circular staple line representing the 'dog ear' site. The remnant linear staple line containing the ECCS/CCS article was targeted for microscopic evaluation and assessment of the tissue healing response.

Briefly, a ventral midline incision was made exposing the descending colon, and site for the proximal anastomosis identified. The colon was transected with either CCS or ECCS device and purse-string created with clamp and suture. A scalpel was used to excise the proximal staple line along the long axis of the purse-string clamp, which was then removed, and the detachable anvil of the intraluminal circular stapler introduced into the bowel lumen. The anvil shaft was secured by standard technique. The trocar of the stapler was advanced through the central region of the linear staple line then connected with anvil prior to closure of stapler instrument. An effort was made to maintain at least one, and preferably, both 'dog ears' (remnants of the transection staple line remaining after application of the circular stapler). The circular stapler was withdrawn, and the resultant tissue "donut" examined. A second anastomosis procedure was then conducted as detailed above a minimum of 5 cm distal to the first anastomotic site (towards the rectum) using the applicable device.

An intraoperative leak test was performed after each anastomosis by blocking the colon several centimeters proximal to the first anastomosis and distending with air *via* rectal catheter. Warm saline was added surrounding anastomotic segments and anastomoses examined for presence of air leakage into saline filled abdomen. After lavage with warm saline, the abdomen was evacuated prior to routine closure of laparotomy incision.

On day 7 or 21 (± 1), pigs were euthanized, and a necropsy performed. Gross changes at the anastomotic sites, including but not limited to serosal adhesions, mucosal ulceration, and evidence of post-operative bleeding, infection or leak were documented. The segment of colon with anastomosis was incised to expose the lumen, attached to a laminate sheet, and stored in 10% NBF. Following fixation, specimens containing the ECCS and CCS article (i.e. remnant linear staple line) located in the area of the 'dog ear' site was targeted during trimming for microscopic evaluation (Figure 4). Specimens were X-rayed prior to trimming to assist with location of the remnant ECCS/CCS article. Tissues were embedded in Spurr's resin for thin-section microtomy, mounted on glass slides and stained with H&E stain. Histopathologic evaluation of inflammation, inflammatory cell composition, tissue healing response, mucosal epithelium regeneration at the anastomotic staple line, and surgical trauma was performed via light microscopy using an Olympus BX46 brightfield microscope (Olympus, Tokyo, Japan). The type and extent of tissue changes at the anastomosis were documented and compared between devices. Tissue and cellular response were subjectively scored as follows: 0= absent; 1= minimal; 2= mild; 3= moderate; 4= marked or severe.

### Leak onset pressure testing

Leak onset pressure and rate of staple line leaks which formed at 30 mmHg in harvested porcine colon (thickness = 3.14 ± 0.24 mm) were compared between ECCS and Endo GIA™ Ultra Universal Stapler with Tri-Staple™ 2.0 Radial Intelligent Reload (EGIAUSTND/SIGRADMT) (GIA). Testing was performed using a proprietary positive pressure liquid test system capable of pressurizing sealed tissue and recording leak onset pressure as briefly described here. Harvested colon tissue was slid onto an appropriate diameter adapter and secured. The length of tissue from the staple line to mandrel was controlled. Pressure into the sealed colon segment was increased using a stepwise function at a rate of 1 mmHg every 2 seconds until leakage or 100 mmHg was achieved, whichever came first. Raw data was collected including leak onset time and leak onset pressure. Analysis was performed using Minitab 17 (Minitab, State College, PA).

### Leak performance was calculated two ways:

**Comparisons for mean leak onset pressure were calculated *via*:**

$$\%\,higher\ onset\ pressure = 100 \times \frac{[(mean\ pressure)_{ECCS} - (mean\ pressure)_{GIA}]}{(mean\ pressure)_{GIA}}$$

A t-test was performed to determine if the average pressure at which leak onset occurred in ECCS was larger than GIA.

**Comparisons for staple line leaks below 30mmHg:**

The percentage of leaks was calculated by comparing rate of failure between ECCS and GIA based upon the number of devices that exhibited leak before or at 30 mmHg. A two sample proportions test was then calculated with Fisher's exact test.

## Results

### Visual and histological evaluations relative to tissue trauma

***Ex vivo* Visual compression-related tissue trauma analysis:** Final analysis (n=30 CCS and n=30 ECCS) demonstrated significantly less tissue damage observed with the ECCS device 46.3% ± 20.2% when compared to CCS device 74.46% ± 9.69% (P<0.001) (Figure 3).

### *Ex vivo* Histological compression-related tissue trauma testing

**CCS device:** a total of nine slides originating from six samples created by application of the CCS device were evaluated. Seven slides had tissue sections which originated from areas with visible tissue damage and two slides had tissue sections from areas without visible damage. Tissue sections from areas with visible gross damage had complete loss of the mucosa (7 out of 7 slides), and in addition some of these sections had partial loss of the submucosa (4 out of 7 slides). Tissue sections originating from areas without tissue damage had no microscopic changes except for a single tissue section where minimal mucosal epithelium damage was noted.

**ECCS device:** A total of nine slides originating from six samples created by application of the ECCS device were evaluated. Four slides had tissue sections that originated from areas with visible tissue damage, four slides had tissue sections from areas without visible damage and one slide had a combination of these. Tissue sections from areas with visible gross damage had complete loss of the mucosa (5 out of 5 slides) and in addition some of these sections had partial loss of the submucosa (2 of 5 slides). Tissue sections originating from areas without tissue damage had no discernible microscopic changes.

***In vivo* survival study - tissue healing response:** A total of

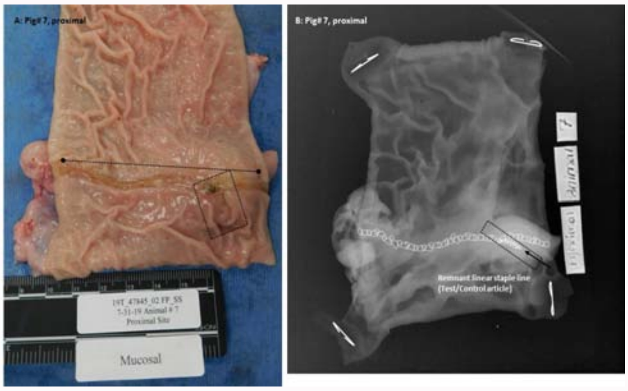


**Figure 4:** Tissue trimming at the 'dog ear' site. Left: gross image of the anastomosis showing the circular staple line outlined by dotted line and the 'dog ear' site (squared area). Right: X-Ray image of the corresponding gross image (Left) showing the remnant linear staple containing the ECCS/CCS article (arrow) targeted for tissue trimming. Pig# 7, proximal anastomosis.

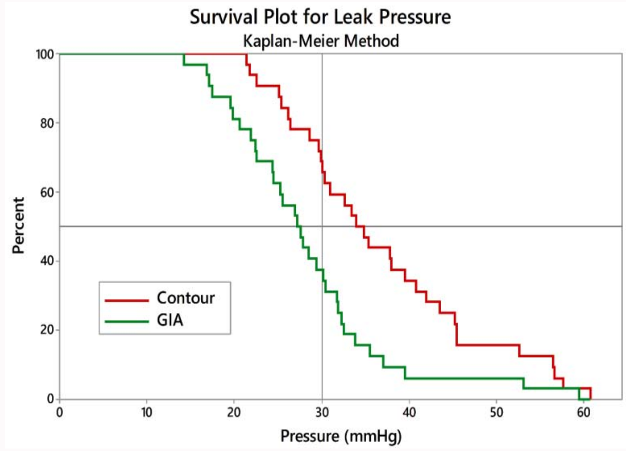


**Figure 5:** Survival plot of leak pressure for ECCS and GIA staplers with reference lines for median (50%) and 30 mmHg.

18 animals were utilized for this study of which 16 survived to termination and were included in the evaluation. One animal was euthanized during surgery due to complications with the anastomotic procedure. One animal was euthanatized at day 4 post-operatively due to sepsis caused by a perforated gastric and spiral colonic ulcer. Neither case was associated with complications at the anastomoses or with application of the test or control device. Gross and microscopic findings in both anastomoses in this animal were within the expected range and no abnormalities were noted. Across the remaining 16 animals, a total of 8 colonic anastomoses (4 proximal and 4 distal) for each ECCS/CCS article were created within each time point.

**Gross findings:** Gross findings at anastomoses with CCS or ECCS were comparable. The proximal anastomoses with the CCS had adhesions to the adjacent structures at a similar frequency as noted with the ECCS anastomoses. None of the adhesions with either device anastomoses were associated with serositis/peritonitis, leak or infection.

**Histopathology findings:** Microscopic findings at the 'dog ear' sites containing the remnant staple line were comparable between CCS and ECCS at both study intervals. The tissue healing response to ECCS was acceptable at each study interval and was within the expected range for this type of procedure. At 7 days, the ECCS staples were directly surrounded by a combination of macrophages and/or fibroblasts and by compressed tissue. As a result of procedure-related tissue trauma, the tissue adjacent to the staples was often infiltrated by small amounts of fibroblasts and macrophages, and occasionally, eosinophils. The type and severity of the tissue response with the CCS staples was comparable to that noted with the ECCS staples. The type and severity of tissue response at the anastomotic defect were similar in the anastomoses performed by both devices. At the anastomosis defect, the intestinal cut margins were bridged by fibroproliferative tissue infiltrated by mixed-type inflammation (macrophages, neutrophils, eosinophils) and the serosa was often mildly thickened by fibrous tissue. Mucosal epithelium regeneration was often minimal at this time interval.

At 21 days, the ECCS staples were directly surrounded by a combination of macrophages and/or fibroblasts and compressed tissue. Staples were often partially surrounded by concentric layers of macrophages and fibroblasts infiltrated by low amounts of eosinophils. This change is attributed to the pressure applied by the staples on the adjacent tissue and is not a direct response to the staples. The type and severity of the tissue response with the CCS staples was comparable to that noted with the ECCS staples. The tissue response at the anastomotic defect was similar in type and severity in anastomoses performed with both devices. At the anastomosis defect, the intestinal cut margins were bridged by fibroproliferative to fibrous tissue infiltrated by mixed-type inflammation (macrophages, neutrophils, eosinophils) and the serosa was often mildly thickened by fibrous tissue. Mucosal epithelium regeneration ranged from minimal to almost complete epithelial regeneration at this interval.

**Leak onset pressure testing:** A statistical difference was observed between the ECCS (n=32, 36.9 ± 11.1 mmHg) and GIA (n=32, 28.2 ± 9.6 mmHg) in relation to the mean leak onset pressure (P=0.002) demonstrating that the ECCS had a 30.8% higher mean leak onset than that of the GIA. A 2-sample proportions test to evaluate rate of staple line leaks at 30 mmHg showed a statistical difference (P=0.011) indicating that the ECCS (n=32, leak rate = 0.281) had significantly fewer leaks (55% less) than the GIA (n=32, leak rate = 0.625) (Figure 5).

## Discussion

Historically the standard approach to colorectal procedures was via open surgery [15]. Gradually, the advantages of the laparoscopic approach, notably smaller incision length, less blood loss and postoperative pain, and faster recovery compared to open procedures, has led to increased popularity of this route [16-17]. These advantages additionally improve economic outcomes for hospitals and patients [18]. There are, however, challenges with the laparoscopic approach for surgeries with large or heavy tumors, if there is reduced tactile feedback or inadequate exposure to the site [19]. Laparoscopic surgery is especially difficult in rectal cancers because of the complex anatomy in the region of the rectum, in particular in the deep pelvis of males. Other obstacles that may make open surgery the only viable option are extensive lesions, thick bowels or advanced disease [20]. Additionally, depending upon the instrumentation used, the learning curve for laparoscopy may be prolonged, requiring a large number of procedures to acquire a high level of competence [21].

Recently, hybrid techniques have been found to be a viable option, wherein laparoscopic splenic flexure takedown is followed by infra-umbilical midline laparotomy. Such a procedure has resulted in smaller incisions and shorter hospital stay [22]. Whether pursuing an open, laparoscopic or hybrid technique, the instrumentation used, and especially the surgical stapler, is of the utmost importance in achieving positive outcomes in colorectal surgery. Stapling has been shown to provide both improved outcomes and reduced adverse events when compared to hand-sewing of sutures for anastomosis in open colorectal surgery [23]. The CCS device with its small head combining both cutting and stapling into one device is commonly utilized globally in colorectal surgery. This study compared the new ECHELON CONTOUR™ Curved Cutter Stapler to its predicate device regarding tissue trauma, tissue healing response, and staple line integrity with additional testing comparing staple line leaks between the market competitor and the ECCS device.

An important requirement for successful surgical interventions involves the gentle handling of tissue to avoid tissue trauma and this is particularly true in patients with tissue compromised by inflammatory bowel disease, radiation and other comorbidities [24-26]. Benchtop *ex vivo* testing confirmed significantly less tissue trauma was observed on the mucosa of the porcine colon with the ECCS device when compared with the CCS. The novel GST technology integrated into the new ECCS device precisely compresses tissue specifically where staples are deployed thereby potentially reducing force between staples.

In preclinical testing, the ECCS device was found to be comparable to the CCS device. Specifically, gross findings from in vivo testing demonstrated that the ECCS device showed an overall acceptable tissue healing response at the remnant linear staple lines when compared to the CCS device at both study intervals. Additionally, gross findings at the anastomoses with the ECCS and CCS article were comparable with adhesions to the adjacent structures at a similar rate at both 7- and 21-days - none of which was associated with serositis/ peritonitis, leak or infection. Microscopic findings and assessment of tissue healing at the “dog ear” sites were also comparable between devices at both study intervals and both were within the expected range. Adverse responses, such as exacerbated tissue reaction, bleeding, leak or infection or delayed tissue healing were not noted in any of the anastomoses with either ECCS or CCS device. Addressing the continued risk of anastomotic leaks which challenge surgeons performing LAR [27].

3D stapling, with the offset closure of staple lines, demonstrated a reduction of leak pathways when compared with Two-Dimensional (2D) stapling leading to significantly fewer leaks at staple lines when compared to the GIA. By providing compression at the staple and reducing compressive forces between the staples while maintaining sealing efficacy, the ECCS device demonstrated a 55% lower staple line leak rate at or below 30 mmHg when compared with the Endo GIA™ Ultra Universal Stapler with Tri-Staple™ 2.0 radial intelligent reload potentially improving clinical consistency and usability leading to improved clinical outcomes. Additional internal simulations confirmed improved staple line integrity. Computational simulations were performed based upon Finite Element-Based Analysis (FEA) to mimic the approximation of tissue during closure and the formation of 2D and 3D staples during firing. During testing, geometric factors were controlled between the two simulations (staple geometry and material, driver geometries, and cartridge-side platen), excepting the anvil pocket which was varied to represent 2D and 3D geometries. Movement speeds, distances, dwell times for staple loading, compression, staple firing, and decompression were also controlled between the two simulations. GST was excluded from the simulated cartridge deck to allow unobstructed comparison between the two staple forms without introducing variables due to GST compression. These simulations further demonstrated that the ECCS device produces more even compression along the staple line resulting in an overall 13.1% improvement in compression between ECCS and CCS staples. Comprehensive compression analysis showed a significant reduction in the average standard deviation in 3D staples versus 2D Staples (P=0.003). The area of maximum difference resulted in up to a 24.7% improvement in comprehensive compression between 3D staples *vs.* 2D staples (Bonnett P=0.001, Levene P=0.016).

The ECCS device embodies all the previous functionalities of the CCS device with the addition of GST and 3D stapling technology. Studies outlined here demonstrate that the ECCS device will potentially lead to improved staple line integrity and less tissue trauma which are risk factors associated with leak risk thereby possibly improving clinical outcomes. Moving forward, additional clinical evidence will need to be gathered to further confirm this.

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