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Mentoring Console Improves Collaboration and Teaching in Surgical Robotics

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ABSTRACT

***Background*: One of the most significant limitations of surgical robots has been their inability to allow multiple surgeons and surgeons-in-training to engage in collaborative control of robotic surgical instruments. We report the initial experience with a novel two-headed da Vinci surgical robot that has two collaborative modes: the "swap" mode allows two surgeons to simultaneously operate and actively swap control of the robot's four arms, and the "nudge" mode allows them to share control of two of the robot's arms.**

***Materials and Methods*: The utility of the mentoring console operating in its two collaborative modes was evaluated through a combination of dry laboratory exercises and animal laboratory surgery. The results from surgeon-resident collaborative performance of complex three-handed surgical tasks were compared to results from single-surgeon and single-resident performance. Statistical significance was determined using Student's t-test.**

***Results*: Collaborative surgeon-resident swap control reduced the time to completion of complex three-handed surgical tasks by 25% compared to single-surgeon operation of a four-armed da Vinci ($P < 0.01$) and by 34% compared to single-resident operation ($P < 0.001$). While swap mode was found to be most helpful during parts of surgical procedures that require multiple hands (such as isolation and division of vessels), nudge mode was particularly useful for guiding a resident's hands during crucially precise steps of an operation (such as proper placement of stitches).**

***Conclusion*: The da Vinci mentoring console greatly facilitates surgeon collaboration during robotic surgery and improves the performance of complex surgical tasks. The mentoring console has the potential to improve resident participation in surgical robotics cases, enhance resident education in surgical training programs engaged in surgical robotics, and improve patient safety during robotic surgery.**

INTRODUCTION

The developing field of surgical robotics has a great deal to offer surgeons in the practice of minimally invasive surgery.[1] The high-definition, magnified, three-dimensional view of the operative field afforded to the surgeon by the da Vinci surgical system (Intuitive Surgical, Sunnyvale, CA) is spectacular, and the instinc-

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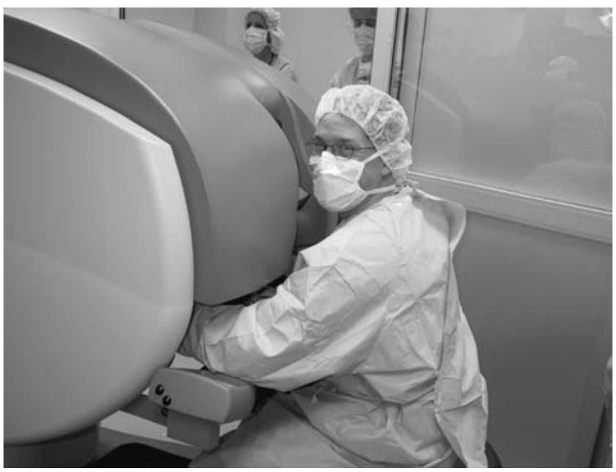

FIG. 1. Photographs from the first robotic case done in the United States military, on February 15, 2002. **A:** The attending surgeon's chief resident is hunched over the patient (because the bed could not be raised after the robot was engaged) retracting the gallbladder. Notably absent is the attending surgeon who is **B:** sitting comfortably at the console in the corner of the room, isolated from the remainder of the operative team.

tively controlled articulating instruments are a significant improvement in dexterity and ergonomics compared to those used in conventional laparoscopy.[2]

While the advantages of robotic surgery have inspired accomplished laparoscopic surgeons to investigate the potential of surgical robotics to broaden their application of the minimally invasive surgery paradigm,[3] a number of limitations retard the widespread adoption of this technology into general surgery practice. Cited limitations of surgical robotics include the cost of current systems,[4] their physical obtrusiveness in the operating room, their inability to provide haptic feedback, their limitations with respect to four-quadrant abdominal surgery,[3] and—the focus of this study—the limited teaching capability and collaborative potential of current-generation surgical robotic systems.[5]

The inherent physical nature of console-driven surgical robots limits physical intraoperative collaboration between surgeons, and limits the ability of attending surgeons to teach residents.[6] The problem is illustrated in Figure 1, from the first robotic case done in the United States military by our group, on February 15, 2002. Fig. 1A shows the robot and a number of assistants standing tableside. In this case, the attending surgeon's chief resident is hunched over the patient (because the bed could not be raised after the robot was engaged) retracting the gallbladder amidst a sea of robotic arms (with which his head will collide twice during the case). Notably absent from the photo is the attending surgeon who is sitting comfortably at the console in the corner of the room (Fig. 1B). While this exaggerated "first" case certainly represents an extreme, it illustrates the point that current-generation surgical robots severely limit collaboration and resident education during surgery. While the physical separation of the surgeon's console from the patient allows the surgeon to be completely immersed in the visual representation of the operative field, it also isolates him from the rest of the operative team.[1] Collaboration between the surgeon and tableside assistants may occur through an intercom system (if one is present), verbal discussion across the room (which can be challenging in a noisy operating room environment), or through hand signals with the robotic instruments themselves. Because the single-seat console controls all functions of the robot, participation in a robotics case is "all-or-none"—you are either in the driver's seat, or you are a passenger. This lack of middle ground often makes faculty surgeons reluctant to allow residents to sit at the console, as it is extremely difficult to maintain complete control of the operation from tableside.

The premise of this study is that the inability to allow multiple surgeons and surgeons-in-training to engage in collaborative control of robotic instruments is one of the most significant limitations of current-generation surgical robots. In an effort to address this shortcoming, we developed a novel two-console da Vinci system configuration that allows two surgeons to swap and share control of the robot's four arms. We describe the initial experience with this mentoring console and characterize its ability to improve the robot-assisted performance of complex three-handed surgical tasks, and its utility in an animal model of robotic foregut surgery.

MATERIALS AND METHODS

Robotic system

The da Vinci mentoring system is a novel "two-headed" prototype that uses two standard da Vinci consoles linked together via a special-purpose hardware/software connection. Each unit is fitted with an in-console microphone and speaker system that allows collaborating surgeons and surgeons-in-training to communicate easily. The two consoles can be placed side-by-side (Fig. 2A) or on opposite sides of the patient (Fig. 2B)—the two-way voice system eliminates potential communication problems that might otherwise occur by having the consoles physically separated. The bedside robotic unit is a standard four-armed da Vinci unit.

The da Vinci mentoring system can be operated in three different modes: swap, nudge, and average. Swap mode allows all three of the da Vinci's robotic instrument arms to be operated simultaneously—one or two by one surgeon and two or one, respectively, by the second surgeon. Swap mode includes the ability to swap control of each instrument on the fly, so that at any time the resident can transfer control of one instrument to the attending and vice versa. Nudge mode allows for only two instruments to be controlled at one time (as during normal single-surgeon da Vinci operation), but allows the two surgeons to simultaneously control and/or feel the exact movement of the instruments. Average mode allows collaborating surgeons to contribute to the control of a robotic instrument based on a mathematically calculated weighted average of multiple console movement inputs. This mode of operation was not investigated in this study.

Experimental design

After a brief introduction to the various modes of operation of the mentoring system, we tested the performance of the system on a three-handed surgical dry laboratory task designed to test the limits of normal single-surgeon da Vinci operation (during which only two of the three instrument arms can be used at one time). The collaborative Penrose drain task simulates stepwise transection of a mesentery or progressive dissection through a surgical tissue plane. Repeated measures (n = 10) of collaborative performance by a single junior-level resident (EJH, with research experience in both laparoscopic and robotic surgery) and a single attending (MRM, with extensive clinical experience in laparoscopy and robotic surgery) on this task were compared to repeated performance on the same task by the resident alone and by the surgeon alone. The collaborative Penrose drain task combines the two basic minimally invasive surgery skills of grasping and cutting. The instruments in the left and right robotic arms are graspers and are controlled by

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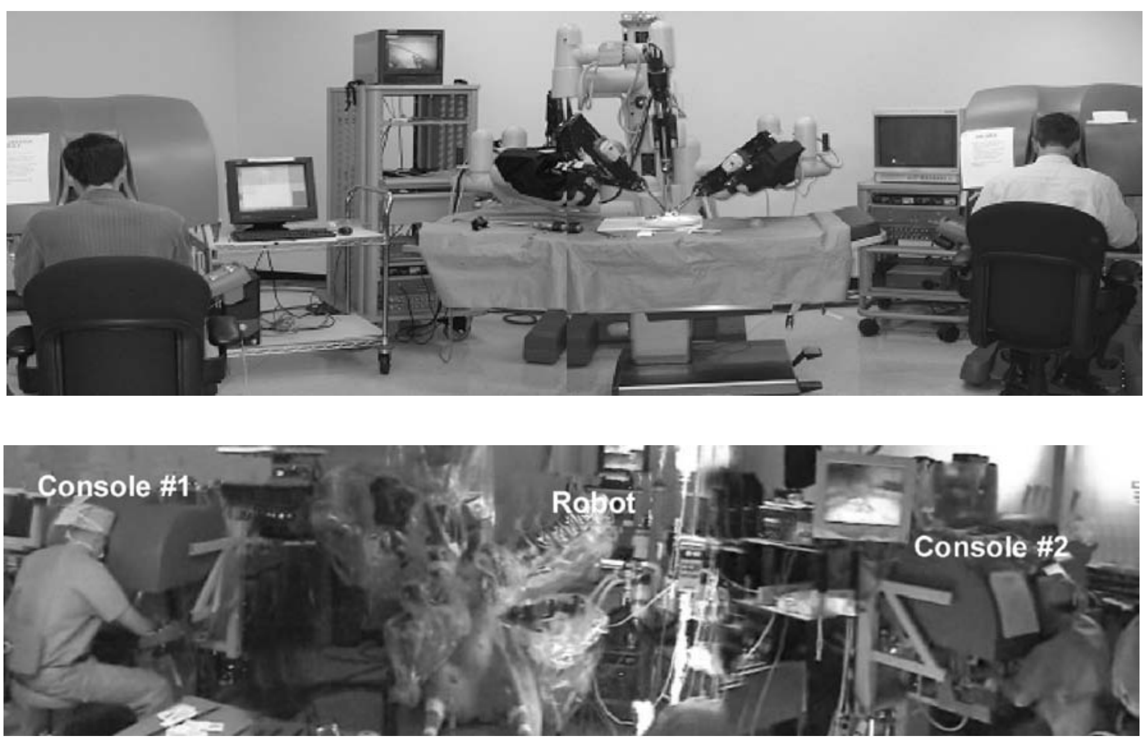

FIG. 2. The da Vinci mentoring system is a novel "two-headed" prototype that uses two standard da Vinci consoles linked together via a special-purpose hardware/software connection. Each unit is fitted with an in-console microphone and speaker system that allows collaborating surgeons and surgeons-in-training to communicate easily with one another. The two consoles can be placed **A:** side-by-side or **B:** on opposite sides of the patient.

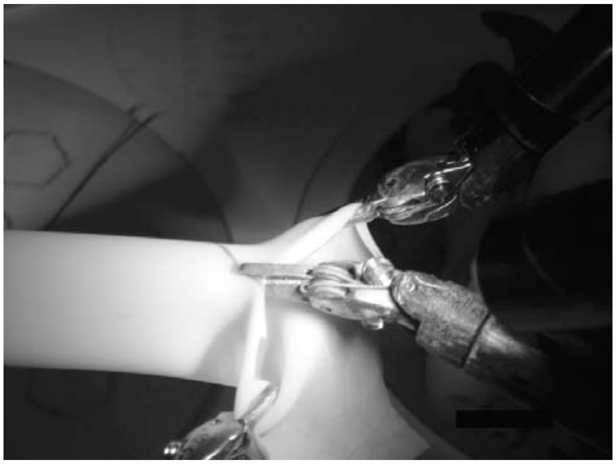

FIG. 3. The collaborative Penrose drain task. The instruments in the left and right robotic arms are graspers and are controlled by one of the two surgeons. The third instrument arm has a pair of scissors controlled by the second surgeon. The goal of the task is for the two surgeons to work together to completely filet open a Penrose drain, cutting along a standardized, pre-drawn curvilinear line running the entire length of the drain.

one of the two surgeons. The da Vinci's third instrument arm has a pair of scissors controlled by the second surgeon. The goal of the task is for the two surgeons to work together to completely filet open a Penrose drain, cutting along a standardized, pre-drawn curvilinear black line running the entire length of the drain (the line is drawn using a cosine wave pattern such that the line crosses the natural fold of the drain multiple times, making the task more challenging since the inherent shape of the drain works against the surgeon). The surgeons are encouraged to work as quickly as possible with the caveat that their incision must remain on the line at all times (Fig. 3). The roles of the two surgeons are defined at the beginning of each trial, with each surgeon performing either the grasping or cutting function. The primary endpoint is time to completion of the task.

After inanimate model testing, the utility of the mentoring system operating in both swap and nudge collaborative modes was evaluated in a porcine model of foregut surgery. All members of the operative team made qualitative observations during da Vinci mentoring-system-assisted laparoscopic Nissen fundoplication in pigs. Focus-group style debriefings were conducted at the end of each day of testing to assimilate this data. The modes of operation were varied throughout the course of the operations and were tailored to best facilitate safe progression of the operation being collaboratively performed by a resident and attending general surgeon. All procedures were part of an animal protocol reviewed and approved by the Intuitive Surgical Inc. Animal Care and Use Committee.

Statistical analysis

Mean time to completion of the complex three-handed surgical Penrose drain task for surgeon-resident collaborative performance was compared to that of single-surgeon and single-resident performance. Statistical significance of the differences between these means was determined using Student's *t*-test. Analysis was performed using Microsoft Excel (Microsoft Corporation, Seattle, WA) and SigmaStat (SPSS Incorporated, Chicago, IL) software.

RESULTS

Performance on the collaborative Penrose drain task by the surgeon-resident team operating the da Vinci mentoring system in swap mode was compared to single-surgeon and single-resident performance. Mean time to completion of the task by a single resident operating the da Vinci robot in the standard configuration was 3.50 ±

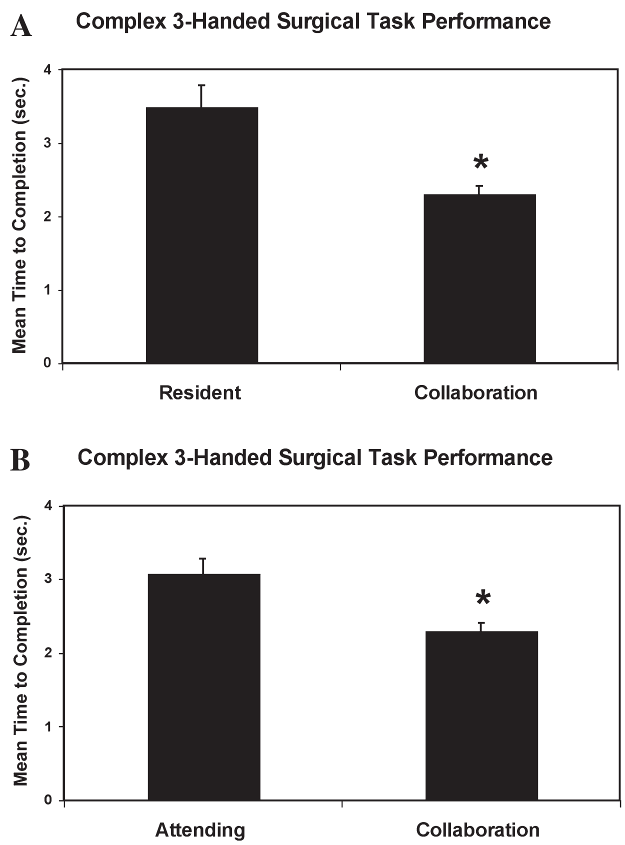

FIG. 4. **A:** Collaborative surgeon-resident control in swap mode reduced the mean time to completion of the Penrose drain task by 34% compared to single-resident operation (*$P < 0.001$), and **B:** by 25% compared to single-surgeon operation of a four-armed da Vinci (*$P < 0.01$).

0.29 minutes. The mean time to completion of the same task by a single attending surgeon was 3.08 ± 0.19 minutes. Collaborative control by a surgeon-resident team reduced the mean time to completion of the task to 2.30 ± 0.11 minutes. This represents a 25% reduction in task completion time compared to single-surgeon operation ($P < 0.01$) and a 34% reduction compared to single-resident operation ($P < 0.001$) (Fig. 4).

Both swap and nudge collaborative modes of the mentoring system were qualitatively evaluated in a porcine model of foregut surgery. During laparoscopic Nissen fundoplication in pigs, swap mode was found to be most helpful during parts of the operation that required multiple instruments operating simultaneously. For example, when the short gastric vessels were being divided, swap mode allowed the surgeon to fluidly "walk up" the fundus of the stomach, presenting each vessel to the resident for division without pausing to switch control to the third instrument arm. Swap mode was also useful when dissecting out the crura and the retroesophageal space. During the crural repair and the fundoplication, the team found nudge mode particularly helpful, as the attending was able to guide the resident's hands for proper stitch placement.

DISCUSSION

While surgical robots have not yet been proven to produce superior clinical outcomes in general surgery,[3] it would seem that the potential benefits of advanced surgical telemanipulator devices is so great that it is simply a matter of time before the "right" robot is developed for general surgery.[7] In the meantime, surgeons are investigating the use of the current-generation surgical robot (da Vinci) to determine its niche in general surgery. A large percentage of surgical robots in clinical use are owned by academic medical centers, the majority of which have residency training programs in general surgery.[8] Unfortunately, the nature of the da Vinci robot makes it exceptionally "resident-unfriendly"—so much so, that the majority of residents at our programs prefer not to be involved in cases in which the robot is used. The inherent physical configuration of remotely operated surgical robotic systems limits the type of collaboration that surgeons normally enjoy at the operating table during open and conventional laparoscopic surgery.

The nature of the da Vinci robot (you are either in control of the operation or you are an assistant) frequently leads attending surgeons to relegate the resident to the role of tableside assistant. Because laboratory training on the robot is expensive[2] and difficult to integrate into already stretched residency programs, a step-wise introduction of the robot to residents is exceedingly difficult.[9] What was envisioned in the da Vinci mentoring system was a "driver's ed" version of the da Vinci robot that would fill the gap between tableside assistance and console control, enable collaborative robotic surgery, and improve resident education in training programs that participate in surgical robotics.

The current study demonstrates proof of concept for a novel surgical robotic mentoring console and shows that

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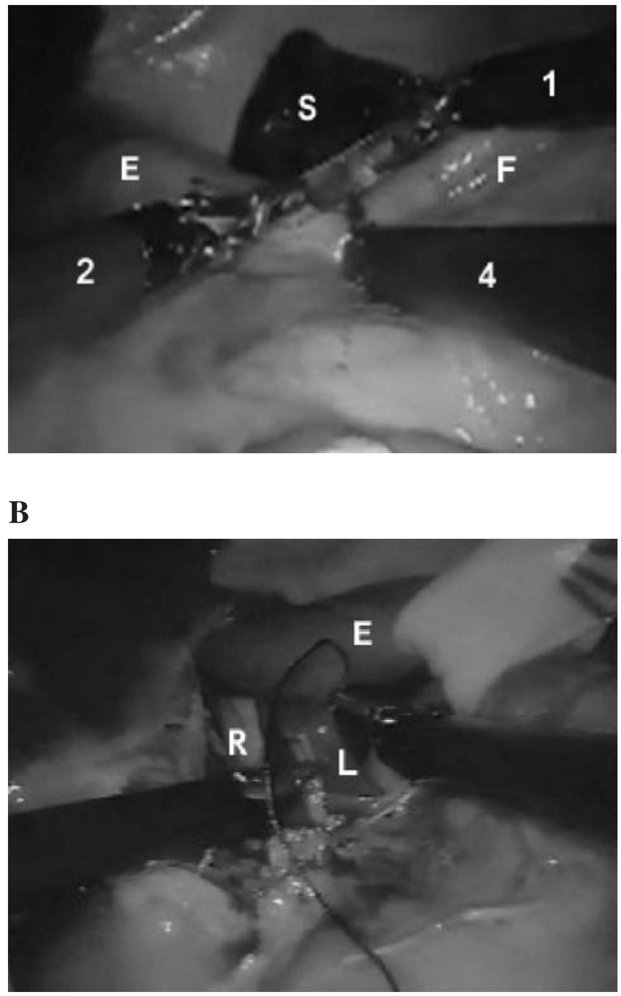

FIG. 5. During laparoscopic Nissen fundoplication, swap mode was found to be most helpful during parts of the operation that required multiple instruments operating simultaneously. **A:** When the short gastric vessels were being divided, swap mode allowed the surgeon to fluidly "walk" up the fundus of the stomach past the spleen toward the esophagus using the two main instrument arms, and present each vessel to the resident for division without pausing to switch control to the third instrument arm (the 4th arm) (F, fundus; S, spleen; E, esophagus; 1, 2, 4, the three instrument arms). **B:** During the crural repair, the team found nudge mode particularly helpful, as the attending was able to guide the resident's hands for proper stitch placement through the left and right crura behind the esophagus (L, left; R, right; E, esophagus).

the mentoring system improves the robotic performance of a complex surgical task compared to standard robotic operation. The combination of dry laboratory exercises and an animal model of porcine foregut surgery in this study allowed for a variety of operative processes on which to test both the swap and nudge modes of the collaborative robotic system.

Single-surgeon and single-resident performance on the Penrose drain task takes longer simply because the true capability of the robot is not being appropriately leveraged. During single-person da Vinci operation a great deal of time is wasted on arm switching, and the dynamic combination of traction, counter-traction, and cutting to which we are accustomed in surgery is replaced by a slow, rigid, and choppy process that is neither efficient nor satisfying. When the same tasks are performed using two-person collaborative robotic surgery in swap mode, the operation looks like a normal operation, with three arms continually working together to accomplish the task. This represents a straightforward return to what surgery is supposed to be, and to what most surgeons would agree is a better way to operate.

While the swap mode of the mentoring system represents a solution to a problem that was initially created by the technology of surgical robotics itself, nudge mode represents a significant advance in all of surgery—the opportunity for which was created as a consequence of the technology.

Nudge mode allows for only two instruments to be used at one time, but allows the two surgeons to simultaneously control and/or passively feel the movement of the instruments. This is similar to the dual-yoke system afforded a pilot and co-pilot pair in most airplanes (flying being another skill for which it is not appropriate to transition immediately from passenger to pilot).

The tremendous potential for this feature was made apparent in our study during the first animal operation performed with the mentoring system (Fig. 5). In this case, a Nissen fundoplication was being performed by an experienced gastrointestinal surgeon with videoendoscopic expertise and a junior level general surgery resident who was naïve to this operation. As the crural repair was initiated, the resident commented that he was unsure where the first stitch should be placed. In nudge mode, the attending surgeon was able to show him how to do it, with the resident's hands moving in his console exactly as they were moving in the attending's console. After the demonstration, the needle was backed out of the tissue and the attending said to the resident, "OK, now you do it." Having just felt with his own hands exactly how the maneuver was supposed to occur, the resident was able to place the stitch in a manner remarkably reproducing the attending's stitch. Had the resident still not been able to place the stitch precisely where the attending wanted it, the mentor could have nudged the resident's hands in the middle of the move to further guide and train the resident in placing the stitch properly. From the perspective of the resident, this was truly the best way to learn—it was as though the attending had his hands wrapped around the resident's hands, physically training him to move in the correct way.

In the future, a combination of modes may be available to allow simultaneous swap control of some instruments and nudge control of others. Future studies of the da Vinci mentoring system should investigate whether or not the mentoring console has the potential to improve patient safety during robotic surgery compared to single-robotic-surgeon cases in which the resident is operating the console. The addition of a mentoring console to the da Vinci surgical system creates the potential for further work toward collaborative telesurgery in which experienced sub-specialists may be able to guide less experienced surgeons through difficult cases from thousands of miles away.[10–14]

CONCLUSION

Our study shows that the prototype da Vinci mentoring system facilitates surgeon collaboration during robotic surgery, improves performance of complex three-handed surgical tasks compared to single-surgeon robotic operation, improves resident participation in surgical robotics cases, and has the potential to enhance resident education in surgical training programs engaged in surgical robotics. Of the various modes of operation available in the mentoring system, swap mode was found to be most useful for accomplishing tasks requiring multiple hands, whereas nudge mode was found to be most helpful when a crucially precise step was called for. The mentoring system has the potential to improve patient safety in hospitals with both active surgical robotics programs and surgical residency training programs.

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