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Article

Nintendo Da Vinci: A Novel Control System to Improve Performance in Robotic-Assisted Surgery

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SUMMARY
Complications of robotic-assisted surgery are on the rise, partly due to surgeons not receiving proper training. Using the current Da Vinci (DV) surgical system, surgeons require anywhere between 150 and 3,000 surgeries to achieve adequate proficiency. To improve performance, we have developed a new system using Nintendo Joycon (NJ) controls. We hypothesized the NJ controls would improve surgical performance, so we compared the NJ and DV systems with two user groups (doctor and gamer). The doctor and the gamer performed a defined task using NJ and the DV control systems, in a simulated skills assessment in 2-dimensional (2D) and 3D modes. The task completion time and error rate were used to calculate a Fundamentals of Robotic Surgery Skills Assessment (FRS) score. The FRS was then used to calculate the learning rate using the learning rate formula. The task completion time, error rate, FRS scores, and the learning rate were significantly better with NJ. The error rate risk ratios indicated that the DV control system carried a higher risk of error compared to the NJ control system. The NJ control system was associated with a better task completion time by 83% for the doctor and 88% for the gamer, a lower error rate by 73% for the doctor and 82% for the gamer, better FRS score by 72% for the doctor and 46% for the gamer, and better LR by 84% for the doctor and 86% for the gamer. This study shows that implementing a NJ control system is associated with improved surgical performance and LR compared to DV.

INTRODUCTION
It is a national mission to reduce surgical morbidity, reduce healthcare costs, and accelerate learning for training and practicing surgeons (1-3). Robotic-assisted surgery is being implemented to complete this mission. The Federal Drug Administration approved the Da Vinci Surgical System in 2000. Only Da Vinci Surgical Systems are used for robotic surgery and are in 3,800 hospitals worldwide (4). The system itself costs upwards of $2 million in acquisition and maintenance (5). Therefore, many surgeons do not have the necessary training on it. Over the past few years, complications associated with robotic-assisted surgery have skyrocketed (5). This is likely due to surgeons not completing the recommended training, which requires surgeons to perform at least 150-3,000 surgeries to be proficient in robotic-assisted surgery. Many surgeons only do between 50-120 procedures, which is ineffective and may potentially endanger patients (6). In fact, the frequency of complications associated with robotic surgery is grossly underreported, so it isn't possible to find exactly how many injuries and deaths result from robotic surgery (7). Patients often need to travel to distant cities to find a surgeon qualified to do robotic-assisted surgery (8).

To address this issue and reduce the risk of complications, we developed a new surgical system to replace the current Da Vinci control system with an easy-to-use Nintendo Joycon control system. To our knowledge, our study is the first to do this. We selected Nintendo Joycons for this study because the Nintendo Switch Joycon has more advanced technology, enabling more precise movements of the Da Vinci Surgical System, and the controls feel natural, making it easy to use (9). The Da Vinci controller has ergonomic issues which the Joycon can fix such as comfort and an efficient design. Many doctor trainees are familiar with the Nintendo Switch Joycons. In fact, 80% of students in medical school play videogames (10). We hypothesized that an easier control system would reduce the amount of training surgeons need to be proficient by accelerating the learning curve and reducing operating (task completion) time, and errors. We used 3D models of the Da Vinci controllers and official Nintendo Joycons for our experimentation. A gamer was used because of their proficiency in using the Joycons. Our results found the Nintendo Joycon control system significantly improved performance by improving FRS scores, reducing error, reducing task completion time, and accelerated the learning rate.

RESULTS
A doctor and a gamer each performed seven Fundamentals of Robotic Surgery Skills Assessment (FRS) (see methods section) pegboard tasks for each test (n = 7 Nintendo Joycon 2D, n = 7 Nintendo Joycon 3D, n = 7 Da Vinci 2D, n = 7 Da Vinci 3D). The pegboard task is a test that trains a surgeon the fundamental skills needed in robotic surgery by using the task completion time and error from moving rings between poles to calculate an FRS score. The Nintendo Joycon control system and the Da Vinci control system were used in the simulated Fundamentals of Robotic Surgery Skills Assessment (FRS) in

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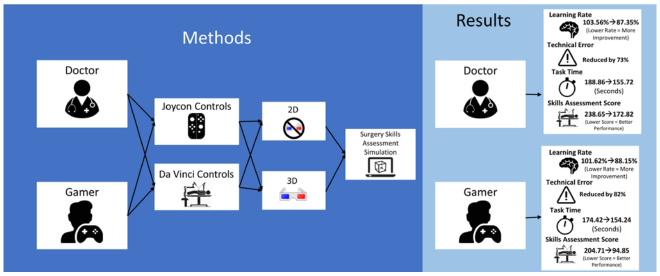

Figure 1. Visual summary of the study. The left side shows a flow chart of the procedure and the right side shows the results collected.

2D and 3D by both users (**Figures 1 and 2**). A doctor and a gamer were recruited to show that no matter whether the user has prior experience with the Joycons, there will still be a significant improvement in surgical performance with the Joycon system compared to the Da Vinci system. Sessions 1 and 2 tested whether the Nintendo Joycon control system improved simulated surgical performance for the doctor in 2D (session 1 is 2D Nintendo Joycon, and session 2 is 2D Da Vinci). We found a statistically significant decrease in mean task time (-33.16 seconds, p = 0.016), mean error (-19.07%, p = 0.015), mean FRS score (-74.06, p = 0.012), and mean learning rate (-28.64%, p = 0.0094) when using the Nintendo Joycons (**Table 1 and Figure 3**). The proportion of tasks with errors favored the Nintendo Joycon control system and was statistically significant (relative risk ratio = 3.0, p = 0.0398) (**Table 3**). Sessions 3 and 4 (3D Nintendo Joycon and 3D Da Vinci) tested whether the Nintendo Joycon control system improved simulated surgical performance for the doctor in 3D. We measured a statistically significant decrease in mean task time (-33.11 seconds, p = 0.016), mean error (-16.73 percent, p = 0.0021), mean FRS score (-66.17, p = 0.0013), and mean learning rate (-3.79 percent, p = 0.047) when using the Nintendo Joycons (**Table 1 and Figure 3**). The proportion of tasks with errors favored the Nintendo Joycon control system and was statistically significant (relative risk ratio = 4.5, p = 0.0451) (**Table 3**). These results indicate the doctor learned the task faster and did so with less error when using the Nintendo Joycons. Sessions 1 and 2 (2D Nintendo Joycon and 2D Da Vinci) tested whether the Nintendo Joycon control system improved simulated surgical performance for the gamer. We measured a statistically significant decrease

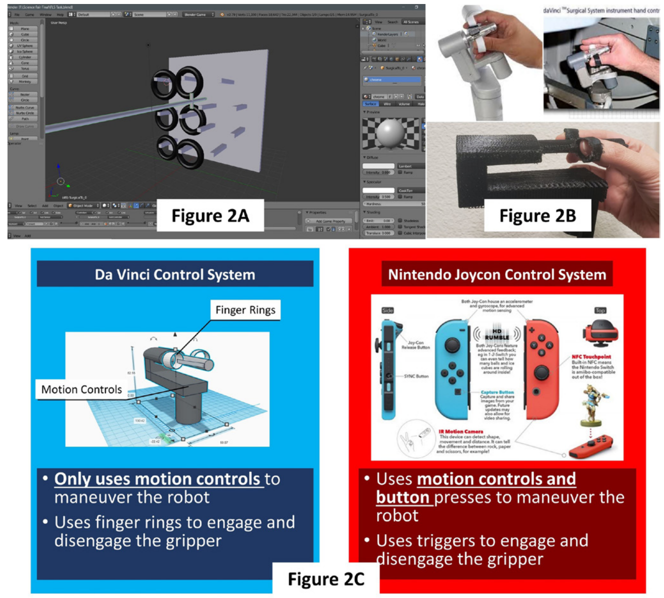

Figure 2. Fundamentals of Robotic Surgery skills assessment (FRS) pegboard task. A) The pegboard task requires moving rings from the left pole to the right pole. B) Top images show the official Da Vinci controller used in modern robotic-assisted surgery and the bottom image is the Da Vinci controller created by the student researcher. C) Comparison of Da Vinci controller and Joycon controller systems. Left image created by author in Tinkercad. Right image from images.nintendolife.com.

2D	Da Vinci (n = 7)		Joycon (n = 7)			
Outcomes	Mean	SD	Mean	SD	Difference	*P* Value
Task Time (s)	206.14	37.86	172.98	31.67	33.16	0.016
Error (%)	28.57	0.76	9.52	0.78	19.07	0.015
FRS Score	265.81	67.97	191.75	56.17	74.06	0.012
Learning Rate (%)	111.09	25.56	82.45	9.82	28.64	0.0094
3D	**Da Vinci (n = 7)**		**Joycon (n = 7)**			
Outcomes	Mean	SD	Mean	SD	Difference	*P* Value
Task Time (s)	171.58	21.47	138.47	13.55	33.11	0.016
Error (%)	21.43	0.49	4.70	0.49	16.73	0.0021
FRS Score	211.50	29.07	145.33	22.49	66.17	0.0013
Learning Rate (%)	96.02	6.93	92.23	5.48	3.79	0.047

Table 1. Outcomes for doctor. Top, 2D simulation. Bottom, 3D simulation. FRS, Fundamentals of Robotic Surgery. SD, standard deviation. s, seconds. A p-value less than 0.05 was considered significant.

2D	Da Vinci (n = 7)		Joycon (n = 7)			
Outcomes	Mean	SD	Mean	SD	Difference	*P* Value
Task Time (s)	137.70	23.23	101.41	16.82	36.29	0.0002
Error (%)	42.86	1.13	7.14	0.53	35.72	0.0009
FRS Score	198.53	34.89	109.39	25.98	89.14	0.0003
Learning Rate	98.61	9.78	86.65	7.21	11.96	0.004
3D	**Da Vinci (n = 7)**		**Joycon (n = 7)**			
Outcomes	Mean	SD	Mean	SD	Difference	*P* Value
Task Time (s)	170.80	25.09	76.52	6.42	94.28	0.000006
Error (%)	23.81	0.98	4.76	0.49	19.05	0.02
FRS Score	210.87	44.55	80.33	11.99	130.54	0.000002
Learning Rate	104.63	8.71	89.66	5.54	14.97	0.008

Table 2. Outcomes for gamer. Top, 2D simulation. Bottom, 3D simulation. FRS, Fundamentals of Robotic Surgery. SD, standard deviation. s, seconds. A p-value less than 0.05 was considered significant.

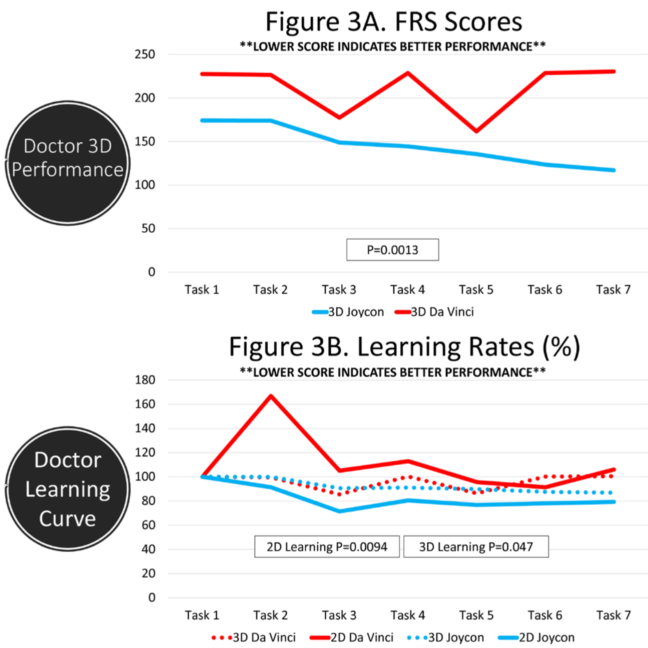

Figure 3. FRS scores and learning curve for doctor in 2D simulation and 3D simulation. A) The doctor's FRS (Fundamentals of Robotic Surgery Skills Assessment) scores for the Joycons and the Da Vinci in the 2D simulation and the 3D simulation. A lower FRS score indicates better performance. B) The doctor's learning curve for the Joycons and the Da Vinci controls in 2D and 3D simulations. A lower learning rate indicates better performance.

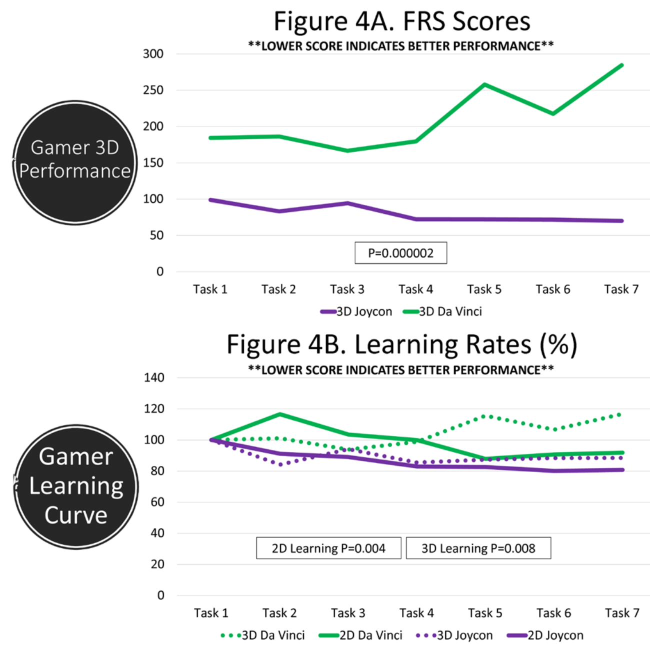

Figure 4. FRS scores and learning curve for gamer in 2D simulation and 3D simulation. A) The gamer's FRS (Fundamentals of Robotic Surgery Skills Assessment) scores for the Joycons and the Da Vinci in the 2D simulation and the 3D simulation. A lower FRS score indicates better performance. B) The gamer's learning curve for the Joycons and the Da Vinci controls in 2D and 3D simulations. A lower learning rate indicates better performance.

in mean task time (-36.29 seconds, p = 0.0002), mean error (-35.72%, p = 0.0009), mean FRS score (-89.14, p = 0.0003), and mean learning rate (-11.96%, p = 0.004) when using the Nintendo Joycons (**Table 2 and Figure 4**). The proportion of tasks with errors favored the Nintendo Joycon control system and was statistically significant (relative risk ratio = 6.0, p = 0.0022) (**Table 4**). Sessions 3 and 4 (3D Joycon and 3D Da Vinci) tested whether the Nintendo Joycon control system improved simulated surgical performance for the gamer. We measured a statistically significant decrease in mean task time (-94.28 seconds, p = 0.000006), mean error (-19.05%, p = 0.02), mean FRS score (-130.54, p = 0.000002), and mean learning rate (-14.97%, p = 0.008) when using the Nintendo Joycons (**Table 2 and Figure 4**). The proportion of tasks with errors favored the Nintendo Joycon control system and was statistically significant (relative risk ratio = 5.0, p = 0.0304) (**Table 4**). These results indicate the gamer learned the task faster and did so with less error when using the Nintendo Joycons. Our data indicates that implementing a Nintendo Joycon control system could significantly improve surgical performance by accelerating the learning rate and by reducing error.

DISCUSSION

We hypothesized that implementing a Nintendo Joycon control system would improve surgical performance on Da Vinci virtual reality tests. We demonstrated that the Joycon control system improves performance and reduces error

2D	Da Vinci (n=7)		Joycon (n = 7)				
Outcomes	Mean	SD	Mean	SD	RR	95% CI	P Value
Error (%)	28.57	0.76	9.52	0.78	3	(1.0523 to 8.5530)	0.0398
3D	**Da Vinci (n=7)**		**Joycon (n = 7)**				
Outcomes	Mean	SD	Mean	SD	RR	95% CI	P Value
Error (%)	21.43	0.49	4.70	0.49	4.5	(1.0333 to 19.5969)	0.0451

Table 3. Risk ratios for doctor. Top, 2D simulation. Bottom, 3D simulation. SD, standard deviation. RR, relative risk. CI, confidence interval. In the simulations, RR = X means that the doctor was X times as likely to have error when using the Da Vinci system compared to the Joycon system. A p-value less than 0.05 was considered significant.

2D	Da Vinci (n = 7)		Joycon (n = 7)				
Outcomes	Mean	SD	Mean	SD	RR	95% CI	P Value
Error (%)	42.86	1.13	7.14	0.53	6	(1.9093 to 18.8546)	0.0022
3D	**Da Vinci (n = 7)**		**Joycon (n = 7)**				
Outcomes	Mean	SD	Mean	SD	RR	95% CI	P Value
Error (%)	23.81	0.98	4.76	0.49	5	(1.1650 to 21.4592)	0.0304

Table 4. Risk ratios for gamer. Top, 2D simulation. Bottom, 3D simulation. SD, standard deviation. RR, relative risk. CI, confidence interval. In the simulations, RR = X means that the gamer was X times as likely to have error when using the Da Vinci system compared to the Joycon system. A p-value less than 0.05 was considered significant.

(**Tables 1 and 2**). The Nintendo Joycon's better functionality and intuitive controls may explain the improved performance compared to the Da Vinci. For example, the Da Vinci only uses the gyroscope and accelerometer to control the robot, while the Joycon uses analog sticks and buttons in addition to the gyroscope and accelerometer. This refines the movement and enables more precise maneuvers than the Da Vinci. The Joycons combine analog and digital controls, which also enhance precision of the maneuvers (11). A review of several studies of digital and analog technology found that digital technology advancements were associated with improved flexibility, programmability, system reliability, sensitivity to parameter variation, and easier system integration (11). While the Da Vinci may be more sophisticated, that may not be its most important quality. Developers of Nintendo games rely on the intuitive controls and ease-of-use rather than sophisticated controls to appeal to the majority of people and to ensure its widespread use. This is a fundamental observation because, to date, no studies have been made concerning implementing a new control system such as the Nintendo Joycon control system in robotic-assisted surgery. Furthermore, these results show that if virtual reality results are consistent with real results, then when Joycon control systems are implemented, operation times should decrease, complications should decrease, and the learning curve should accelerate. Decreased operation times would widen accessibility to patients since the surgeons may have more time for additional operations. Decreased complications would reduce healthcare costs. Accelerated learning would also reduce healthcare costs since less money would be spent on surgical training, surgeons would have more time to work. Also, it would increase accessibility to patients since more surgeons would be qualified to perform robotic-assisted surgery. The Joycon control system could potentially save a lot of money because it is much cheaper than the Da Vinci control system. Also, since an 84% acceleration in learning was observed, the amount of procedures surgeons need for proficiency could be significantly reduced from between 150-3,000 procedures down to between 20-420 procedures using the Joycon control system.

There were some key limitations in this study that should be mentioned. First, we did not use official Da Vinci controls manufactured by Intuitive Surgical due to the limited accessibility and the high cost of the controls, which is upwards of two hundred thousand dollars. To circumvent this issue, a 3D model of the Da Vinci controls was created, and the accelerometer and gyroscope of the Nintendo Joycon were integrated into the model (**Figure 3**). The same gyroscope and accelerometer were used in the Da Vinci controller as the Joycons to keep the sensitivity of the motion-sensing technology controlled and accurately test the impact of the Joycon controller design.

Second, the findings were unambiguous in a virtual reality setting, yet the true test of the Joycon control system will need to be in the operating room. This was not possible given the circumstances because the Da Vinci surgical system robot costs about on average two million dollars. The fundamental research in the robotic virtual reality setting, however, highlights the potential benefit of employing a Joycon control system for improving patient outcomes and reducing costs. These findings may be easily translatable into the OR due to the parity between the simulated FRS skills assessment and the real FRS skills assessment.

Potential future experiments include testing more complex surgical tasks such as ligating loops, suture strength, round incision, and camera targeting, in addition to the pegboard task. These tasks are widely accepted by the Society of American Gastrointestinal and Endoscopic Surgeons and the American College of Surgeons, and are used to train surgeon fundamentals in robotic surgery that can be translated to the operating room. The ligating loop task and the suture strength task both train the surgeon how to suture the incision and how to estimate how much pressure and force the robot is exerting on the patient. The round incision task trains the surgeon how to be precise and how to maneuver the robot in complex environments. The camera targeting task trains the surgeon how to maximize the efficiency of the camera by figuring out the optimal placement and the direction the camera is facing.

The fact that the authors serve as subject participants in this study potentially introduces a bias in observation, data recording, and interpretation. However, we felt this was not a major concern because we designed this as a pilot study with the intention for validation in future studies. For validation, more subjects will be recruited, excluding the authors as study subjects, to address the small sample size and eliminate that potential bias. The next steps of this study include improvement in the Joycon design by incorporating the strengths of the Da Vinci system, such as the higher end gyroscope to further improve the range of motion.

In conclusion, implementing a Nintendo Joycon control system improved robotic surgery task performance and reduced errors for the doctor and the gamer in a virtual reality setting. Further investigation is required to see if these results translate to the operating room. Our data provides a foundation for future predictive validation studies assessing the role of implementing a Nintendo Joycon control system for improved patient outcomes, reduced operative cost, and paves the way for investigation of this novel control system in all areas of robotic surgery.

METHODS

Subject selection

A pediatric nephrologist with minimal surgical experience in biopsies from Driscoll Children's Hospital and a 15-year-old gamer (gamer defined as someone who spends more than 5 hours playing video games per week) from Veterans Memorial High School were recruited for this study. Neither the doctor nor the gamer had experience with the Da Vinci system, but the gamer was familiar with the Nintendo Joycons.

Robotic surgery systems

The simulation was made in Blender3D using models provided by Intuitive Surgical. The Nintendo Joycon control system was integrated into the simulation and the use of JoyToKey software to translate the controller button presses into key presses for Blender3D to read. The Joycon control system is a hardware add-on which uses the Da Vinci software. The Da Vinci control system was 3D printed and integrated into the simulation by incorporating the Joycon's accelerometer and gyroscope in the Da Vinci control 3D model. This was purposely done since the same gyroscope and accelerometer were used and the precision and accuracy were controlled. For both systems, the motion controls were converted into key presses using the JoyToKey software, as well.

Task design

Both users received 5 minutes of practice prior to performing the Fundamentals of Robotic Surgery Skills Assessment (**Figure 2A**). Seven tasks were performed by each user using the Nintendo Joycon control system in 2D and 3D and using the Da Vinci control system in 2D and 3D, for a total of twenty-eight tasks for each user. The task consisted of a pegboard with twelve poles: six on the left side arranged in a rectangle formation and six on the right arranged in a diamond formation (**Figure 2A**). The users had to move the rings from the left side to the right side. This task was designed to test fundamental skills needed in the operating theatre including hand-eye coordination, bimanual dexterity, speed, and precision. Task time started when the user touched the first ring with the surgical instrument and ended when the last ring was released by the instrument. Each dropped ring counted as 16% error. The skills acquired from the peg transfer task directly translate into better bimanual handling of needle and other small objects during surgery (12). The pegboard task is endorsed by the American College of Surgeons and approved by both, the Food and Drug Administration and the Advanced Medical Technology Association. Each task had 3 levels of difficulty: low, intermediate, and high based on the distance and angle the rings in the simulation module had to be moved during the task.

Performance metrics

The primary outcomes analyzed were task time, error frequency, learning rate, and FRS score for each user using each control system in 2D and 3D modes. The results of the gamer and the doctor were analyzed separately to show if the individual's simulated surgical performance improves when using the Nintendo Joycon control system compared to the Da Vinci control system. The tasks were completed in four sessions: session 1 tested both users using the Nintendo Joycon control system in 2D, session 2 tested both users using the Joycon control system in 2D, session 3 tested both users using the Da Vinci control system in 2D, and session 4 tested both users using the Da Vinci control system in 3D. Each session was separated by a time period of one week to mitigate the potential for compounded learning from previous sessions.

Based on existing surgical curricula validation studies, the following performance metrics were tracked in the simulated skills assessment:

1. Mean task time (seconds) = (sum of task times) / (number of tasks)
2. Technical errors (percentage) = ((number of rings dropped) / (total rings moved)) × 100%
3. FRS score (lower is better) = (task time in seconds) + (% error × task time in seconds)
4. Learning rate (percentage) = 10^{(ln[(FRS Score of *n*th Task)/(FRS Score of first Task))×log(2)]/[ln(*n*th Task)]}

Statistical methods

The primary comparison was a test for the mean difference between the results when using the Joycon control system and the Da Vinci control system. The users were not compared to each other because this study was focused on improving a given user's individual performance. Student's t-test was used to test for a significant difference between study groups, and a p-value < 0.05 was considered statistically significant. Mean and p-value calculations were made in Microsoft Excel. To calculate the significance of error, the relative risk was calculated using an online risk calculator. The name of the website is MedCalc Statistical Software.

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