The Emergence of Surgeon-Controlled Robotic Surgery in Urologic Oncology

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Abstract The rise of robotic surgery is transforming medicine. In many ways, urology has taken charge in pioneering a new era of minimally invasive surgery with the emergence of the robot. The unprecedented dissecting precision and the dynamic three-dimensional, high definition view of the surgical field are undoubtedly revolutionizing the field of urology. These unique attributes of robotic surgery confer enormous advantages in dealing with uro-oncological surgery. The robotic revolution began nearly a decade ago with surgeon-controlled robotic radical prostatectomy and has since expanded to include radical cystectomies and partial nephrectomies. There have been numerous landmark studies published showing that robotic surgery provides comparable oncological and functional outcomes against traditional open or laparoscopic surgery. As a result, it becomes exceedingly imperative that urologists and the oncological community remain up-to-date regarding these developments and appreciate the oncological outcomes of surgeon-controlled robotic surgery. This review will assess the impact surgeon-controlled robotic surgery has had in the field of urologic oncology.

Keywords Robotics · Urologic cancer · Robot-assisted radical prostatectomy · Robot-assisted radical cystectomy · Robot-assisted partial nephrectomy

Introduction

Urology is an inventive and proactive surgical discipline, which has resulted in remarkably improved outcomes for patients around the world. It were urologists who devised and experimented with endoscopic surgery nearly a century ago at a time when other surgical disciplines still held fast to the notion that bigger incisions meant better operations [1]. Today, urology continues to lead in surgical breakthroughs, with the most recent emergence being surgeon-controlled robotic surgery.

Although laparoscopic urologic surgery has been around for decades [2], it has been plagued with some serious drawbacks since procedures are still difficult to perform and there is a steep learning curve for surgeons [2, 3]. Surgeon-controlled robotic surgery using the da Vinci Surgical System (Intuitive Surgical, Sunnydale, CA) adds the benefits of laparoscopic surgery, notably decreased estimated blood loss (EBL), shorter hospital stay and improved functional outcomes with unique advantages of a shortened learning curve, 15-fold 3D magnification and immaculate wrist dexterity [2–4]. The commonly noted limitations of robotic surgery, however, are the over-dependence on the patient side surgeon, high costs and the lack of tactile feedback [3, 5]. Prior to the recent advent of the fourth arm of da Vinci S/Si surgical system, the assistant surgeon performed tasks often done by the principal surgeon [6]. The implementation of a new fourth robotic arm, however, now provides the console surgeon significant autonomy from the surgical assistant [6]. On the other hand, the

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concern over diminished tactical feedback is vastly eclipsed by superior visual clarity and dexterity of the robotic instruments [3]. Additionally, tactile feedback is still retained with the patient side surgeon, who can easily provide insight to the principal console surgeon if need be [3]. The issue with high cost stems largely because robotic surgery is a new and upcoming technology. However, with greater adoption at high volume medical centers around the world, costs can be better moderated [3].

At the end of the day, however, surgeon-controlled robotic surgery is intended chiefly to improve patient outcomes. Nowhere is this more true and significant than in oncological outcomes for cancer patients undergoing surgeon-controlled robotic radical prostatectomy (SCRPP), surgeon-controlled robotic radical cystectomy (SCRRC) and surgeon-controlled robotic partial nephrectomy (SCRPN).

This article will provide an overview of recent developments and oncological outcomes in surgeon-controlled robotic surgery in the treatment of various urologic malignancies and then discuss the future direction of robotic surgery in urologic oncology.

Methods

A MEDLINE search was performed for keywords such as “robot-assisted surgery”, “laparoscopy”, “robot-assisted prostatectomy”, “robot-assisted radical cystectomy”, “robot-assisted partial nephrectomy” to name a few. Articles were selected that correlated with the scope of the topic with special consideration given to recently published articles.

Prostate

Prostate Cancer

In 2008, an estimated 903,500 new cases of prostate cancer (comprising 14% of all new cancer cases) were diagnosed worldwide with 258,400 deaths [7]. This makes prostate cancer the second most frequently diagnosed and sixth deadliest cancer on the globe [7]. The objective of any surgical intervention for prostate cancer is to cure the patient by removing the prostate gland, seminal vesicles and sometimes the pelvic lymph nodes, while concurrently preserving sexual function and continence [8].

In 1982, Walsh and Donker [9] first introduced a nerve-sparing technique for retropubic open radical prostatectomy [9, 10]. The surgical approach attempts at preserving sexual function and was the gold standard in treating localized prostate cancer [10]. Open prostatectomy, however, is

highly associated with significant urinary incontinence, sexual dysfunction and postoperative complications [8]. In pursuit of reducing complications of open prostatectomy, a minimally-invasive surgical technique was developed by Schessler and colleges in 1992 known as laparoscopic radical prostatectomy (LRP) [11]. Unfortunately, LRP was not adopted by most urologic surgeons due to the technical demands and a long learning curve needed for mastery [10].

It was not until the emergence of the da Vinci Robotic Surgical System in 1999 that minimally invasive surgery truly became standardized [10]. Surgeon-controlled robotic surgery intrigued surgeons largely for the technological prowess: three-dimensional vision, seven degrees of freedom, little to no blood loss and reduced postoperative complications [2, 3, 10].

Technique

The prostatectomy technique combines a transperitoneal approach with extraperitoneal techniques of dissection as learned from open surgery [12]. The patient is put in a Trendelenburg position and the robot is brought into position over the patient's abdomen between the legs [12]. The large bowel is mobilized and the extraperitoneal space is entered with a U-shaped incision on the anterior peritoneum superior to the dome of the bladder [12]. The incision is medial to the internal inguinal ring bilaterally and at this point the vas deferens can be transected or preserved [12]. The incisions are subsequently joined anteriorly and the bladder is dropped from the anterior abdominal wall [12]. Next step is to proceed to divide the bladder neck anteriorly in the midline and the Foley catheter is pulled upward from the incision and grasped by the assistant, thus retracting the prostate upward [12]. Dissection is now performed underneath the prostate until the vas deferens and the seminal vesicles are identified [12]. Tremendous care is taken to carefully dissect these structures and their accompanying blood vessels [12]. It has been shown that the internal iliac nodal basin is the primary landing zone for lymph node metastases from prostate cancer, and thus bilateral pelvic lymphadenectomy is now performed in nearly all prostate removals [12].

For further discussion and detail on the prostatectomy technique, particularly nerve sparing, and other surgical techniques for SCRPP consult pp. 236–241 in *Robotics In Genitourinary Surgery* [12].

Oncological Outcomes

Even with aforementioned benefits of surgeon-controlled robotic surgery, the most critical question was whether this new surgical technique produced equivalent or better oncological outcomes for patients with prostate cancer.

In one of the largest follow-up studies to date, Menon et al. did a complete follow up on 1,142 patients who underwent SCRRP [13]. The median follow-up time was 36 months [13]. Menon et al. found that their SCRRP technique achieved comparable oncological outcomes to conventional nerve-sparing radical prostatectomy while offering 84% of patients total urinary control at a mean 12 month follow-up [13].

In order to further evaluate long-term oncologic outcomes, Menon et al. evaluated 1,384 patients with localized prostate cancer who underwent SCRRP with a focus on 5-year biochemical recurrence-free survival (BCRFS) between 2001 and 2005 [14]. Menon and his colleagues defined biochemical recurrence (BCR) as serum prostate-specific antigen >0.2 ng/ml and evidently found at a median follow up of 60.2 months 189 incidences of BCR (31 per 1,000 person years of follow up), of which 13 patients developed metastatic disease and 7 subsequent deaths [14]. With these results, Menon et al. suggested that compared with other treatment modalities for prostate cancer, SCRRP conferred effective 5-year biochemical control [14].

Open or robotic, a radical prostatectomy procedure always aims to achieve three critical post-operative and long-term outcomes, known among urologists as the 'trifecta': 1) patient stays cancer free; 2) patient retains urinary continence; and 3) patient retains potency [15].

Patel and his team evaluated trifecta outcomes of RARP performed by a single highly experienced surgeon [15]. Patel et al. evaluated 1,100 consecutive SCRRP patients and found the trifecta rates at 6 weeks, 3, 6, 12 and 18 months were 42.8%, 65.3%, 80.3%, 86%, and 91%, respectively [15]. The study also showed that compared with older men, younger men had higher trifecta rates at 6 weeks, 3 and 6 months after RARP ($P < 0.01$ at all time points) [15]. Patel and colleagues, therefore, concluded their study showed RARP provided excellent short-term trifecta outcomes [15].

In aim to present astute clinical evidence, Parsons et al. performed a systematic review and meta-analysis comparing outcomes of radical retropubic, laparoscopic and robotic-assisted prostatectomy [16]. Parsons and his team used 19 studies (3,893 patients) for the meta-analysis and concluded that compared with retropubic prostatectomy, patients undergoing robotic-assisted prostatectomy showed no significant difference in overall risk of positive surgical margins [16].

In the treatment of localized prostate cancer, radical prostatectomy remains the standard of care for long-term cure and survival, with cancer-specific survival at nearly 95% at 15 years [15]. Now, however, younger and healthier men are undergoing PSA screening, resulting in the early detection of organ-confined prostate cancer [15]. Although

the chief goal for a radical prostatectomy procedure is to keep the patient cancer-free, problems with urinary continence and potency are especially important to young men [15]. Since SCRRP is proving comparable oncological outcomes coupled with greater postoperative urinary control and improved sexual function than other surgical modalities [13, 16], one can expect the use of surgeon-controlled robotic surgery to continue expanding in the treatment of prostate cancer.

Bladder

Bladder Cancer

In 2008, an estimated 386,000 new cases and 150,200 deaths occurred from bladder cancer worldwide [7]. The probability of developing bladder cancer follows a direct correlation with increasing age. In fact, bladder cancer is now the fourth leading cause of death in patients over the age of 80 [17]. Open radical cystectomy (ORC) has long been the gold standard for treating localized muscle invasive bladder cancer [18]. In 1992, Parra et al. [19]. performed the first laparoscopic radical cystectomy (LRC) in attempts to lower the morbidity commonly associated with the open procedure [18, 19]. The main drawbacks of LRC, however, were again long learning curves for surgeons, morbidity and complications [18]. It was not until Menon et al. performed a successful SCRRP that interest grew for robotic surgery among the urologic community [20]. Guru et al. also performed SCRRP on twenty consecutive patients between 2005 and 2006 and concluded that the procedure can be performed safely for candidates for open cystectomy [21]. In 2010, Allaparthi et al. reported on a consecutive cohort of three patients undergoing surgeon-controlled robotic partial cystectomy (SCRPC) for bladder cancer which expanded the scope of this exciting new treatment modality [22].

Technique

SCRRP in Males

The patient is placed under general endotracheal anesthesia and positioned in steep Trendelenburg position with six port placements [23, 24]. Adhesiolysis is performed and sigmoid colon is mobilized on the left side and ileocecal junction and cecum mobilized on the right side [23]. The goal is to define three avascular spaces: periureteral, lateral pelvic space, and anterior rectal spaces [24]. Lower end of the ureters are divided and sent for frozen section pathologic examination and Hem-o-lok clips are applied

at the proximal end to avoid leakage of urine [23]. Pelvic lymph node dissection is done bilaterally and posterior dissection is performed and peritoneum is divided transversely in cul-de-sac anterior to the rectum [23]. Bilateral lateral dissection is continued to demonstrate vesical pedicles and vesicoprostatic pedicles, which are controlled with a Hem-o-lock clip followed by posterolateral dissection [23]. Urachus and medial umbilical ligaments are divided high to drop the bladder and cystectomy is carefully performed [23].

Further discussion and detail on SCRRC technique in males has been described in pp. 503–510 in *Robotics In Genitourinary Surgery* [23, 24].

SCRRC in Females

Initial steps are the same as described earlier [23]. Obvious changes deal with elevation of posterior vaginal floor, posterior dissection in the rectovesical space, division of the ligamentum teres, and specimen removal via vagina [23]. Further discussion and detail on SCRRC in females has been described previously [23, 24].

Oncological Outcomes

Muscle-invasive bladder cancer is a vicious disease because untreated patients typically have a less than 15% of survival at 2 years [25]. Numerous studies have shown that the ‘quality’ of the radical cystectomy goes a long way in affecting patient survival [25]. Two key prognostic factors to prevent recurrence are maintaining a negative surgical margin and performing an adequate lymphadenectomy [25]. The question naturally arises then, can a new procedure like RARC achieve results with same or better oncological and functional success than ORC?

Pruthi and his team followed a total of 100 consecutive patients who underwent SCRRC from 2006 to 2009 for clinically localized bladder cancer [26]. Pruthi et al. found that in no SCRRC procedure was there a positive surgical margin and 8% of patients subsequently suffered a major complication (Clavien grade 3 or higher) [26]. At a mean followup of 21 months, 15 patients had disease recurrence with 6 eventually succumbing to the disease [26]. Pruthi and colleagues concluded that with their relatively large study to date, SCRRC for the treatment of bladder cancer provided satisfactory outcomes [26]. Nix et al. published a subsequent landmark prospective randomized trial of ORC versus SCRRC in 41 patients and discovered that compared with ORC, SCRRC was associated with less intraoperative EBL (258 vs. 575 ml $P<0.001$), earlier time-to-bowel movement and reduced narcotic use for pain relief [27].

In hopes to advance present knowledge of postoperative outcomes, Martin et al. looked at 80 patients at a mean follow-up of 25 months who underwent SCRRC [28]. Of the 80 patients, 59 were identified as having a follow-up greater than 6 months [28]. Upon analysis of these 59 patients, Martin and his team found the overall survival at 12, 24, and 36 months to be 82%, 72% and 72% respectively [28]. Martin et al. noted that these results were similar to previously published ORC overall survival rates of 87%, 77% and 69% at 12, 24, and 36 months, respectively [28]. Therefore, Martin and colleagues concluded that SCRRC had comparable survival and recurrence rate to ORC [28].

In one of the most comprehensive RARC series to date, Kauffman et al. followed 85 consecutive patients with bladder cancer treated with SCRRC between 2006 and 2008 [29]. At an average postoperative follow up of 18 months, 20 (24%) patients had developed recurrent disease while disease-free survival, cancer-specific survival and overall survival rates at 2 years were 74%, 85% and 79%, respectively [29]. Kauffman and his team elaborated that these 2 year SCRRC survival data is almost identical to contemporary ORC series [29]. To note, however, surgical margins were positive in five patients [29]. Upon univariate analysis, though, margin positivity was significantly associated with extravesical primary tumor ($P<0.01$) and LN positivity ($P=0.024$) [29]. Kauffman et al. explained that their positive margin rates met benchmark standards proposed by Herr et al. at 6% overall (<10% recommended) and 14% with extravesical disease (<15% recommended) [29, 30]. Kauffman et al. concluded that their published 2-year survival outcomes for SCRRC matched those of existing ORC series, while concurrently demonstrating lower rates of local recurrence [29].

Furthermore, Hellenthal et al. used the International Robotic Cystectomy Consortium database and identified 513 patients who underwent SCRRC performed at 15 institutions from 2003 to 2009 [31]. Of the 513 patients Hellenthal et al. found that 6.8% (35) patients had a positive surgical margin [31]. As a result, Hellenthal et al. concluded that these positive surgical margin rates were similar to those in open cystectomy cohort studies [31].

In effort to preserve healthy bladder tissue, Allaparthi et al. published the first study of three patients undergoing SCRRC [22]. At a median follow-up of 6 months, all three patients were alive and had no signs of recurrent or metastasis [22]. Therefore, Allaparthi and his team concluded that their early study showed promise that SCRRC is technically feasible for select patients with bladder cancer and the procedure shows adequate short-term oncological results [22]. We had comparable results at our institution with SCRRC in three patients as well, with mean EBL, hospital stay and mean operative time all within satisfactory limits [32].

Unfortunately, ORC has a realistic cure rate of only 60%, with many patients succumbing to recurrence and eventual death [29]. Early and intermediate follow up studies has strongly suggested SCRRC may provide similar oncological efficacy but with reduced complications and blood loss [27–29]. Although long term oncological and functional data is required, SCRRC holds serious promise in eventually becoming standard treatment for localized bladder cancer.

Kidney

Kidney Cancer

In 2008, the age-standardized rate (ASR per 100,000 people) of kidney cancer among males from developed areas was 11.8% while males from less developed areas stood at 2.5% [7]. For females, the corresponding ASR was 5.8% from developed and 1.4% from less developed regions, respectively [7]. In the United States, particularly, the 5 year survival rate of patients diagnosed with kidney cancer jumped from 51% in the 1970s to 69% in the last decade [17]. One of the contributing factors for developed nations witnessing increased incidence and improved survival from kidney cancer stems largely from the liberal use of computed tomography (CT) and other imaging modalities in the last decade [33]. Patients with incidental renal malignancy found on imaging were often at a lower pathologic stage and grade at diagnosis, which unsurprisingly resulted in improved overall survival post-treatment [33, 34].

The standard treatment for localized renal cancer has long been to simply remove the entire kidney, otherwise known as a radical nephrectomy (RN) [33]. There has been, however, a growing trend toward nephron-sparing surgery. This has been due to three key factors: first, small renal masses are being found at an earlier stage due to the prevalence of imaging for other disease states [35]. Second, it has been found that a partial nephrectomy (PN) yields acceptable outcomes for tumors as large as 7 cm [35]. And third, it has also been found that a RN puts patients at an increased risk for chronic kidney disease [35]. Huang and colleagues did a retrospective cohort study of 662 patients undergoing elective partial or radical nephrectomy for a solitary, renal cortical tumor less than 4 cm [36]. Upon further examination, they noted that 171 (26%) of these patients had pre-existing chronic kidney disease prior to surgery [36]. By following these 171 patients for 3 years, Huang et al. discovered that patients who underwent a RN had a 65% chance of developing chronic kidney disease as opposed to a 20% chance with a PN [36]. In other words, the risk of developing chronic kidney disease after having a

RN is three times greater than the risk associated with having a partial nephrectomy.

While open partial nephrectomy (OPN) remains popular, minimally invasive treatments such as laparoscopic partial nephrectomy (LPN), surgeon-controlled robotic radical nephrectomy (SCRNR) and surgeon-controlled robotic partial nephrectomy (SCRPN) have recently surfaced [32]. SCRPN was first described in 2004 by Gettman et al. [37]. Since then, SCRPN has been widely adopted in high-volume centers, especially in the United States [3].

New and exciting technologies have recently emerged to help improve the visualization of the renal vasculature and the delineation of normal renal parenchyma versus neoplasm with the utilization of near infrared fluorescence (NIRF) using indocyanine green (ICG) [38]. Manny et al. evaluated NIRF by intravenously injecting ICG in 31 patients undergoing SCRPN [38]. Manny et al. discovered that NIRF using ICG safely and effectively delineated the renal vasculature and helped differentiate renal tumors from surrounding normal parenchyma in all patients, with only 1 patient having a positive surgical margin [38]. The promise of such new methods can help possibly decrease the positive margins rate with SCRPN [38].

Technique

Transperitoneal SCRNR

In instances where a significantly large tumor is found on a kidney, the patient undergoes a surgeon-controlled robotic radical nephrectomy (SCRNR) [39]. The patient is turned onto the table in a modified lateral decubitus [39]. Pneumoperitoneum is achieved with a Veress needle to a pressure of 15–20 mmHg [39]. SCRNR is commenced by identifying and incising the white line of Toldt away from the bowel and the bowel is mobilized from the iliac vessels [39]. The gonadal vessel and ureter to the diseased kidney are identified and traced cephalad. Once both renal vein and renal artery are exposed, either endovascular stapler or locking clips are applied to secure and divide the renal artery and vein, respectively and careful dissection of kidney ensues [39]. Generally, adrenal resection is not recommended concurrent with the radical nephrectomy unless there is an upper pole lesion [39]. Lymph node dissection may be performed when indicated [39].

For further discussion and detail on SCRNR, consult pp. 401–410 in *Robotics In Genitourinary Surgery* [39].

Transperitoneal SCRPN

Initial steps are the same as described earlier [33]. The hilar vessels are dissected and proximally positioned vessel

loops are secured with Hem-o-lok clip [33]. The kidney is dissected free of its surrounding fatty tissue with attention on keeping fatty tissue surround the tumor intact [33]. The renal capsule encompassing the tumor is circumferentially marked with monopolar scissors. [33] 50 min prior to clamping the renal artery, an intravenous injection of 12.5 g Mannitol is administered [33]. Laparoscopic bulldog clamps are used to clamp the renal artery or hilar vessels [33]. Renal tumor is then meticulously resected [33]. The repair of the renal defect is done in two layers: the first is by 3–0 Monocryl suture that is used to close defects in the collecting system and renal vasculature and the second layer is completed with Monocryl or Vicryl suture [33]. All sutures are previously prepared with a knot and a Hem-o-lock clip proximal to its knotted end, and with each pass of the running suture a Hem-o-lock clip is passed against the renal capsule and then slid toward the collecting system in order to cinch the repair [33]. Surgicel (Ethicon, Somerville, NJ) bolster may be used, especially for wide defects exceeding 3–4 cm [33]. The renal vessels are then unclamped, vein first and artery second (if both were clamped) [33]. Another 12.5 g Mannitol is given intravenously after confirming hemostasis [33]. The specimen is then extracted in a endocatch I bag [33].

For further discussion and detail, consult pp. 411–421 in *Robotics in Genitourinary Surgery* [40] and corresponding previously described reference [33].

Oncological Outcomes

There are a few important parameters that will solidify a future for SCRPN in the treatment for renal cell carcinoma: intraoperative plus perioperative safety and short and long-term oncologic outcomes [33].

With the advent of LPN, Gill and his team analyzed data on 1,800 consecutive open or laparoscopic partial nephrectomies [37]. Gill et al. discovered that LPN was highly associated with shorter operative time ($P < 0.0001$), decreased operative blood loss ($P < 0.0001$) and shorter hospital stay ($P < 0.001$) [37]. As a result, Gill and his colleagues suggested that LPN was a viable alternative to traditional OPN [37].

With the emergence of SCRPN, Benway et al. evaluated 118 patients undergoing LPN against 129 patients undergoing SCRPN between 2004 and 2008 [41]. Comparison between the two surgical modalities showed no significant differences in positive margin rate, length of hospital stay and intraoperative blood loss [41]. Thus, Benway and his colleagues concluded that SCRPN is a safe and feasible alternative to LPN, possibly even superior to LPN because of the inherent surgical advantages of the robot [41].

To gauge clinical outcomes, Lee et al. compared outcomes between open versus SCRPN [42]. Lee and his

colleagues performed a retrospective review to compare 69 SCRPN with 234 OPN from 2003 to 2010 [42]. Their results showed no significant differences between the two cohorts (SCRPN vs OPN) and the number of patients with positive surgical margins was 0 for SCRPN and 6 for OPN groups [42]. Haber et al. performed a similar study of 75 SCRPN against 75 LPN patients and noted that all surgical margins were negative thus concluding that SCRPN offered comparable outcomes to LPN [43].

Benway et al. performed one of the largest SCRPN series to date and discovered that in 183 patients, only 7 had positive surgical margins (3.8%) with 5 cases of the surgical margins positive for malignancy (2.7%) [44]. In existing literature, the largest OPN series (1,390 OPN procedures) identified a 5.8% positive margin rate [45]. Therefore, Benway and his team noted that SCRPN showed comparable oncological outcomes to OPN [44].

Rogers et al. similarly had a previous large SCRPN series that showed in 148 patients who underwent SCRPN, there was no evidence of tumor recurrence at a mean follow up of 7.2 months [46]. In effort to further reveal oncological outcomes, Scoll et al. looked at 100 SCRPN at a mean followup of 12.7 months and also did not find any evidence of tumor recurrence among the patients. [47]

Dulabon et al. reviewed the outcomes of 466 consecutive SCRPN patients for hilar and non-hilar tumors, the data representing the largest series of its kind [48]. Dulabon et al. concluded with confidence that SCRPN is safe and effective for renal hilar tumors and that there were no increased risk of adverse outcomes compared with nonhilar tumors [48].

Studies to judge long-term oncological and recurrence rates are still being reviewed and will ultimately decide the fate of SCRPN [33]. Successful short-term studies, however, foreshadow a promising outlook on the vitality of SCRPN for the future.

Conclusion

Surgeon-controlled robotic surgery is providing patients with a new surgical option to treat and cure their urologic malignancy. Robotics has truly restructured the realm of urology, allowing urologic surgeons to navigate and see inside the human body on a platform one could have never imagined. When one couples enhanced vision with a shorter learning curve, quicker recovery and excellent oncological outcomes, it is safe to assume that surgeon-controlled robotic surgery will continue making strong headway in the future. With the robot introduced at the turn of the new millennia, long-term data is starting to be gathered and analyzed and results seem very promising.

Conflict of interest None.

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