Ultrasonography-Guided Versus Fluoroscopy-Guided Modified Minimally Percutaneous Nephrolithotomy for Staghorn Calculi: A Comparative Study

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Abstract

Objective: The purpose of this study was to compare the safety and efficacy of ultrasonography (US)-guided renal percutaneous access for modified minimally invasive percutaneous nephrolithotomy (MPCNL) with conventional fluoroscopy-guided access. We also discuss the application of US-guided residual stone searching in one tract or multiple tract procedures.

Patient and Methods: From April 2013 to December 2014, 134 patients with staghorn calculi were randomly separated into two groups (67 in each), namely, US- and fluoroscopic-guided access groups. In the US-guided group, puncturing was performed using a 3.5/5 MHz US probe, whereas fluoroscopy was utilized in the fluoroscopic-guided group. Patient demographics, stone parameters, and pre-, intra- and postoperative outcomes were analyzed.

Results: Both groups were comparable in terms of patient demographic and stone characteristics. The mean ages of the patients were 39.5 [16-67] years old and 41.5 [15-74] years old in the US- and fluoroscopic-guided groups, respectively (p=0.3843). The male to female ratios in the groups were 43/24 and 42/25, respectively (p=0.8599). Successful access was achieved in 97% of cases in the US-guided group and in 100% in the fluoroscopic group (p=0.4962); the success rates of renal unit access in the groups were 97.3% and 100%, respectively (P=0.4967). Compared to the fluoroscopy group, the duration of radiation exposure during the puncture phase and the mean operating time from initiation of puncture to nephrostomy placement were significantly lower in the US group, at 0.1±0.00 minutes vs 1.4±0.34 minutes (p<0.0001) and at 93.5±11.6 minutes vs 125.3±21.2 minutes, (p<0.0001). Two patients in the US group required fluoroscopic adjustment. A significantly higher stone-free rate after the primary operation was observed in the US-guided group than in the fluoroscopic group (92.0% vs 76.7%, p=0.0124) at postoperative day 2. Furthermore, the average hospital stays were 5.1±2.7 and 5.4±2.3 days, respectively, for the US and fluoroscopy groups (p=0.4899). There were no statistically significant differences in the total number of tracts, blood transfusions, or postoperative fever between the groups (p<0.05).

ABBREVIATIONS

PCNL: Percutaneous Nephrolithotomy; MPCNL: Minimally Invasive Percutaneous Nephrolithotomy; US: Ultrasonography; CT: Computed Tomography; SWL: Shockwave Lithotripsy; IVU: Intravenous Urography; KUB: Kidney Ureter and Bladder

INTRODUCTION

Percutaneous nephrolithotomy (PCNL) was first described by Fernström and Johansson in 1976 for the removal of renal calculi via a dilated nephrostomy tract under radiological control [1]. PCNL is considered the treatment of choice for renal calculi larger than 2 cm in diameter, lower calyx stones, and stones in the calyceal diverticulum, where shockwave lithotripsy (SWL) or the ureteroscopic approach cannot achieve good stone clearance [2,3]. Complications frequently associated with PCNL include renal hemorrhage, perforation of the collecting system, urinary tract infection, injury to the surrounding viscera and even loss of the kidney unit [4-6].

According to the various sheath sizes used for dilatation, PCNL can be further divided into standard PCNL (26-30Fr tract size) and minimally invasive PCNL (MPCNL, 11-20Fr tract size). PCNL with a smaller track (Fr 12-18) for stone management was...
reported as early as 1997 by Helal et al., using a 15Fr Hickman peel-away sheath as the working sheath in the removal of three stones of 5-7mm in a 2-year-old child [7]; Jackman [8] and Monga and Oglevie [9] then reported on procedures called mini-perc and mini-PCNL, respectively, as alternative treatment approaches to conventional large sheath PCNL in both pediatric and adult populations. The term “minimally invasive percutaneous nephrolithotomy” (MPCNL) was introduced by Lahme et al., in Germany in 2001 [10]; in this procedure, the authors used a specially designed miniature 12 Fr nephroscope through a 19Fr tract in 19 patients and achieved a 100% success rate. MPCNL is indicated for small stone loads (<2cm), stones in the calyceal diverticulum, and lower pole calyceal stones, as a secondary track for inaccessible or residual fragments to supplement standard PCNL, and in pediatric patients [10]. It has the potential advantage of decreasing the amount of bleeding and trauma to the renal parenchyma [11]. Recently, Abdelhafez et al., [2012] reported that MPCNL was an effective and safe procedure for large renal stones [12], including complex staghorn stones, in their practice. Chinese MPCNL (16-18Fr tract) was reported that MPCNL was an effective and safe procedure for standard PCNL, and in pediatric patients [10]. It has the potential advantage of decreasing the amount of bleeding and trauma to the renal parenchyma [11]. Recently, Abdelhafez et al., [2012] reported that MPCNL was an effective and safe procedure for large renal stones [12], including complex staghorn stones, in their practice. Chinese MPCNL (16-18Fr tract) was reported initially by Li et al., [13-15], based on their 20 years of experience in 4014 cases [10]. With modern instrumentation and technical improvements, Chinese MPCNL has evolved and become standardized and popular in China. It is used to treat adult renal stones of all sizes, including staghorn calculi.

Gaining access to the PCS in PCNL is routinely performed under fluoroscopic guidance [16]. It was reported that fluoroscopy during PCNL exposed patients to nearly double the radiation exposure of non-contrast renal computed tomography (CT) [17]. Although protective gowns can be routinely worn by patients and physicians during this procedure, radiation exposure can still affect the surgical team over the long term [18]. Ultrasonography (US)-guided puncture is an alternative method for percutaneous renal access, which was first reported by Otto [19]. Recently, growing evidence has suggested that US-guided puncture offers the shortest and straightest access to the collecting system with minimal morbidity; most importantly, the advantages of US include the avoidance of radiation and of adjacent and visceral injury and intra-renal vascular injury, shorter access times, a lower rate of operative complications, and a higher stone-free rate [20,21]. It is of particular importance in the pediatric population and in special situations in which the procedure is performed with the patient in the supine position. With improvements in the resolution of B-mode ultrasonography in the last two decades, MPCNL guided viareal-time US has achieved comparable stone clearance rates and operating times to standard large track PCNL [22-25], particularly for localizing residual stones from renal staghorn calculi after auxiliary treatments, such as SWL. In the present study, we compared the efficiency of US with that of conventional fluoroscopy-guided access, focusing on the success rate of renal access, stone-free rate, operating time, duration of hospitalization, and major complications after the procedures, such as bleeding. Finally, we discussed the application of US-guided access for residual stones searching in one tract and multiple tract procedures.

**PATIENTS AND METHODS**

This study was conducted in the Department of Urology, Second Affiliated Hospital of Kunming Medical University, Kunming (Yunnan, China). The Research Ethics Board of Kunming Medical University (Kunming, China) approved the study. The inclusion criteria were pelvic or calyceal staghorn stones; there is no consensus regarding the precise definition of staghorn calculus, so we selected patients with any branched stone occupying a large portion of the collecting system. Patients with kidney anomalies, uncontrolled coagulopathies, and histories of open renal stone surgeries were excluded. All of the patients underwent plain abdominal radiography (kidneys, ureters, and bladder (KUB), in venous urography (IVU), and CT to clarify the size and location of calculi, the anatomy of the upper urinary tract, and the grade of hydronephrosis. The term “partial staghorn” calculus designates a branched stone that occupies part, but not all, of the collecting system, while “complete staghorn” calculus refers to a stone that occupies virtually the entire collecting system [26]. Figures 1A and 1B demonstrate the typical features of complete staghorn calculi on a plain KUB film, IVU, and CT scan. Stone size was measured by tracing the stone outline on KUB film using graph paper. In patients with multiple renal stones, the stone size was calculated on the basis of the length of longest axis of each stone. After a routine preoperative evaluation, 134 patients with staghorn calculi who were candidates for MPCNL were enrolled in our study between April 2013 and December 2014. Informed consent forms were obtained from all of the enrolled patients. The patients were then randomized into the US- or fluoroscopic-guided access group (67 in each group). Residual stone searching was followed by ultrasonography and fluoroscopy thereafter, respectively. The characteristics of the patients, stone parameters, degree of hydronephrosis and urinary tract infections (UTIs) are summarized in Table 1. Both groups were comparable regarding sex, age, and stone characteristics (see Table 1). A detailed preoperative workup, including a complete medical history, physical examination, urine analysis, urine culture, serum creatinine, and coagulation profile, was performed. In patients with UTIs (middle stream urine culture positive), appropriate treatments were administered.

**Surgical technique of modified MPCNL**

The technique was based on that described by Li et al., [15] with minimal modifications. With the patient in the lithotomy position under general anesthesia with endotracheal intubation, a 5Fr ureteral catheter (Boston Scientific, Marlborough, MA, USA) was inserted, anchored and maintained sterile. A 16Fr Foley catheter was inserted into the bladder to provide drainage during the procedure. The preoperative imaging, including KUB, IVU and CT, were reviewed, and a three-dimensional image was constructed regarding the site of the needle entry point, the needle angle relative to the sagittal plane, and how deep the needle should go. Selection of the targeted calyx was based on the calculus location, calyceal configuration, and degree of hydronephrosis in each calyx. In patients with urinary stones in multiple calyces, we attempted to gain access to the most appropriate calyx or calyces as the first track to remove the stones.

**Ultrasound-guided access**

The patient was then repositioned in the prone position. After distension of the system by normal saline via the ureteral catheter, under ultrasonographic guidance (GE LOGIQe, Davis...
Medical Electronics, Inc., Vista, CA USA], an 18-gauge Chiba needle (Cook Medical, Bloomington, IN, USA), using a 3.5 MHz ultrasound probe, was introduced into the papilla of the targeted calyx. In less hydronephrotic systems, saline was injected continuously from the ureteral catheter or from the previous tract in multiple tract procedures to keep the pelvicalyceal system (PCS) dilated during the puncture. Once entry into targeted calyx was confirmed with fluid efflux, a 0.035 inch diameter floppy-tipped guide wire (Boston Scientific, Marlborough, MA, USA) was passed through the needle into the collecting system. The needle was then removed and the tract serially dilated to 20-22 Fr with fascial dilators on the same guide wire. In moderate or severe hydronephrosis, no saline injection was needed. Pressured pulsatile irrigation, generated by a rotary pump (MMC, Guangzhou, China), was used through an 8.0/9.8 Fr rigid ureteroscope (Richard Wolf Medical Instruments Corporation, Vernon Hills, IL, USA) to ensure a clear view. Fluoroscopy was used as an adjunct when there was difficulty in gaining access by US alone. Patients in whom procedures failed in the US-guided group were not transferred to the fluoroscopic group. Residual stones were judged under US through the abdominal window, using saline injection via the ureteral catheter or the endoscope with pulsatile irrigating saline in multiple tract procedures.

Figure 1A shows the typical features of a complete left staghorn calculus on a plain abdominal KUB film (left panel) and IVU (right panel) in a 49-year-old woman. The American Urological Association has suggested that two or more access sites might be required in the treatment of large or complex stones [26]. In our case, based on the preoperative workup and imaging, we decided to create three tracts to achieve complete stone removal. We demonstrated an appropriate tract 2(←2) as the first tract to the targeted calyx. The selected tract 2 (←2) was tailored to the stone location and calyceal configuration in this case because it was convenient for the ureteroscope to access the ureter and other calyces. The parallel calyx, at an acute angle to the puncture calyx, was inaccessible in this case, so two additional tracts were established (Tract ←1 and Tract ←3, Figure 1A). Figure 1B (a-j) shows a multiple-plane CT scan of the left kidney of the same patient. Based on the information from the CT scan, combined with KUB and IVU, we could decide the puncture site for the needle entry point, the ideal needle angle relative to the sagittal plane, and how deep the needle should go in each individual tract. Residual stone searching was performed under the guidance of US, and an additional tract could be inserted as needed. Figure 1C shows tract 3 (tract 3→) dilation under US guidance after procedures for tract 1(tract 1→) and tract 2 (tract 2→).

Fluoroscopic-guided access

For this group of patients, after ureteral catheterization, the patient was turned from the lithotomy to the prone position. Contrast medium was injected through the ureteral catheter, the targeted calyx was identified, and then, under fluoroscopy guidance, percutaneous access was attempted with an 18-gauge Chiba needle. The remainder of the procedure was the same as described for patients in the US-guided group. Stone clearance at the end was judged by a combination of ureteroscope and fluoroscopy in this group.
In both groups, the process of stone fragment removal occurred concurrently with stone fragmentation. Stone fragmentation was achieved with Power Suite™ Holmium Lasers (40-60W). Stone removal was facilitated by retrograde saline flushing (300-400ml/min, pressure of 25-40kPa) through a ureteric catheter by an assistant.

Postoperatively, a double J stent was inserted under endoscopic guidance in both groups. A 14-16Fr silicon drain was inserted as a nephrostomy tube routinely. The saline flushing time was limited to 120 minutes. We discontinued the procedure to minimize perioperative complications if the operative time was more than 150 minutes. Plain abdominal radiography of the KUB and CT were performed on postoperative day 2 to determine whether residual fragments were present. Fragments of 4mm or less were considered clinically insignificant fragments. The nephrostomy was removed on the fourth postoperative day if the patient was stone free, and perurethral catheter was removed the next day. The preoperative, intra-operative, and postoperative data for the two groups were recorded, as shown in Tables 1 and 2, respectively. The primary outcome parameters were successful access, the success rate of renal unit access, and total fluoroscopy time. The secondary outcomes were the operating time (measured from initiation of puncture to the end of placement of the nephrostomy), postoperative fever, length of hospital stay, stone-free rate, and blood transfusion requirement. Urologists experienced in MPCNL, on one surgical team, performed all of the operations.

Statistical analysis

Statistical analysis was performed using Student’s t-test for continuous variables, the Mann-Whitney nonparametric test, and Chi-square test or Fisher’s exact test for categorical variables. A p-value ≤ 0.05 was considered statistically significant.

RESULTS

Table 1 shows the comparative data of US- and fluoroscopy-guided access. The patient demographics including sex, age, BMI, stone parameters (stone laterality, stone type and stone size), and degree of hydronephrosis were comparable in both groups (p<0.05, Table 1). In this study, 2 patients experienced failure in the US group (one patient with calcification at the puncture site, and the other with ankylosing spondylitis). Successful access to the targeted calyx occurred at rates of 97% and 100% with the two procedures, respectively. The success rates of renal unit access were 97.3% in the US-guided group versus 100% in the fluoroscopy-guided group [Table 2], with the success rate slightly less statistically significant in the US-guided group than in the fluoroscopic group (p=0.4962 and p=0.4967, respectively) [Table 2]. A total of 169 percutaneous access tracts were established in 75 renal units in the US-guided group versus 170 percutaneous access tracts in 73 renal units in the fluoroscopic group, with no significant difference between the groups (p=0.9336, Table 2). The mean duration of radiation exposure during the puncture phase was significantly shorter in the US-guided group at 0.1 minute, compared to 1.4 minutes in the fluoroscopy-guided group (p<0.0001, Table 2). Similarly, the mean operative time (from the beginning of securing the patient in the prone position to insertion of the nephrostomy tube) was 93.5±11.6 minutes in the US-guided group versus 125.3±21.2 minutes in the fluoroscopy-guided group, which was significantly shorter in the US-guided group than in the fluoroscopic group (p<0.0001, Table 2). We achieved complete stone-free rates of 92.0% and 76.7% at postoperative day 2, respectively, in both groups, and a significant difference was observed (p=0.0124, Table 2) between the groups. Figure 2 shows evidence of stone-free status after the primary intervention under US-guided access, compared with preoperative imagines (the same patient as shown in Figure 1A).

Postoperative complications, in terms of severe bleeding and postoperative fever, were recorded in both groups. There was no significant difference between the groups regarding transfusion rates during or after the procedures (p=0.6164, Table 2), with two (3.1%) patients in the US-guided group receiving transfusions.
Table 1: Demographics and Clinical Characteristics of Study Populations.

<table>
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<th>Parameters</th>
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<th>Fluoroscopic-guided access</th>
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<td>Moderate (10-20 mm)</td>
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<tr>
<td>Severe (≥20mm)</td>
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<td>3</td>
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<td>Urinary tract infection</td>
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<td>Abbreviation: BMI: Body mass Index</td>
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<td>Values are expressed as mean ± standard deviation unless otherwise indicated.</td>
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<td>a, Student’s t test</td>
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<td>b, χ² test or Fisher’s exact test (proportions)</td>
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versus one patient (1.5%) in the fluoroscopy-guided group. Four patients experienced postoperative fever in the US-guided group, compared to 5 patients in the fluoroscopic group; no significant difference between the groups was found (p=1.0000, Table 2). The length of hospital stay was slightly longer in the fluoroscopic group than in the US-guided group (5.1±2.7 vs. 5.4±2.3 days, p=0.4899).

DISCUSSION

Urolithiasis is a common cause of morbidity in China, with a prevalence of 1-5% nationally; however, in southern China, the lifetime prevalence is 5-10% [27]. Among types, nephrolithiasis is a very common type, constituting more than 80% of cases of urolithiasis [28]. In addition, the incidence of kidney stones has been increasing in China, in association with economic development. Staghorn calculi are branched stones that occupy a large portion of the collecting system. Typically, they fill the renal pelvis and branch into several or all of the calices [26]. Over time, an untreated staghorn calculus is likely to destroy the kidney and/or cause life-threatening sepsis [29,30]. Therefore, complete removal of the stone is an important therapeutic goal to eradicate any causative organisms, relieve obstruction, prevent further...
stone growth and any associated infection, and preserve kidney function. Among the largest challenges to the management of staghorn stones are residual stones, which require the surgeon to strive for a balance between complete stone removal and an acceptable therapeutic end point with acceptable patient morbidity. The published literature indicates that residual fragments can grow and be a source of recurrent UTIs [31], so the implementation of practical and effective clinical strategies for the management of staghorn calculi for the improvement of quality of life and cost reduction is very demanding.

There are four modalities identified as management options, including percutaneous nephrolithotomy (PCNL) monotherapy, combinations of PNL and SWL, SWL monotherapy, and open surgery [26]. PCNL is still considered the gold standard treatment for choice for renal calculi more than 2 cm in size or for staghorn stones, based on the most current version of the American Urological Association guideline on staghorn calculi [26,32]. Practically, a smaller track (Fr 12-18) is used by many surgical teams instead of a Fr 30 conventional track, with fewer bleeding complications. Chinese MPCNL is a standardized and popular practice for the management of large and complex stones, such as staghorn stones, in both adult and pediatric populations in China. It evolved over many years of practice before the technique, equipment, and setup were standardized [13]. It is less invasive than standard PCNL with less risk of bleeding. One of important features of this technique is kidney puncture based on pre-op imaging and intra-op tactile feedback. The strategy of stone fragment removal by pulsatile irrigation and flushing is another important concept. The process of stone fragment removal occurring concurrently with stone fragmentation contributes to the shorter operative time, compared with traditional PCNL [33].

There are several options for the needle guidance during renal puncture access, including fluoroscopy, ultrasonography, and CT guidance. Recently, many surgical teams have demonstrated the advantages of using US-guided access during the procedure for renal puncture, in terms of intra-operative parameters and postoperative outcomes [34-36]. The advantages include lack of ionizing radiation, a shorter procedure time, a decreased number of punctures, and avoidance of contrast agent administration. All of the studies showed that totally US-guided PCNL was a safe alternative to the traditional fluoroscopic technique [28,37,38]. In our study, 2 cases in the US group (3%) required fluoroscopy as an adjunct, whereas none of the patients experienced treatment failure in fluoroscopy-guided puncture group. Therefore, training in both techniques is required for effective access in all situations. Basiri et al. [39] reported that the success rate for achieving access to the collecting system under US guidance was similar to that with fluoroscopy-guided access. In our study, we confirmed our findings: the rates of successful access and successful renral unit access in the US group were similar to those in the fluoroscopy group (97% vs 100%, p=0.4962 and 97.3% vs 100%, p=0.4967, respectively). Gupta et al. [40] reported a success rate of 98.5% for PCNL under real-time US guidance, and our observations were similar to their reports.

The radiation exposure time in the US group was significantly shorter than in the fluoroscopy group (p<0.0001), consistent with two randomized studies by Basiri et al. [39] and Agarwal et al. [41], which compared US with fluoroscopic-guided PCNL (41.4 vs 57 seconds, p=0.0001 and 14.4 vs 28.6 seconds, p<0.01, respectively). Although the radiation dose during the procedure is within safe limits clinically, the lowest radiation exposure is always preferred [18,28]. We did not compare the time required to achieve the puncture, the mean duration of access, the mean number of punctures, and the number of attempts between the groups.

The true value of the US-guided technique lies in the possibility of it being used as the sole guidance for performing PCNL in properly selected patients, for example, the feasibility of its use in pregnancy, transplanted and anomalous kidneys, and radiolucent calculus [38]. The present study also demonstrated that the use of ultrasonography at the end of the MPCNL procedure could help the urologist in seeking residual stones. It is well established that, as the burden of residual fragments increases, the length of the follow-up period required, the complication rates and the need for auxiliary interventions increase as well [42]. The advantages are more prominent when there are non-opaque and semi-opaque stones that cannot be visualized by radiography [39]. Figure 1D shows a typical picture of the application of US to guided residual stone searching in the management of complex staghorn stones. Figure 1D1 shows an ultrasonicographic view without saline instillation, so the echogenic shadow cannot be clearly observed. However, with saline instillation to increase PCS dilatation, the stone shadow was clear (Figure 1D2). This evidence indicated that US guidance facilitated more thorough inspection of the whole collecting system and provided for more accurate assessment of kidney residual stone status. Although flexible nephroscopy is the gold standard for diagnosing residual stones after PCNL [38], US guidance avoids unnecessary fluoroscopic exposure, as shown in the present study.

We further compared the secondary outcomes related to this procedure between the two groups. The operative time in the US group was significantly shorter than that in the fluoroscopic group (p<0.0001). The stone-free rate after postoperative day 2 was significantly higher than that in the fluoroscopy-guided group (p=0.0124), as assessed by CT. Figure 2 shows the evidence of stone-free status with US-guided procedures in the same patients. No significant difference was observed between the groups regarding the blood transfusion rate (3.1% and 1.5%, respectively, p=0.6164).

There were limitations in the present study. We applied prone positioning in all of the patients during the procedures. In some reports, use of flank positioning, particularly in obese patients, has resulted in less restriction of respiratory-dependent movement of the chest wall, facilitating ventilation and anesthesiologic access to the endotracheal tube [35]. Moreover, in the flank position, US is highly capable of detecting calculi, and access to the PCS is easier according to Karami et al.’s report [35]. We were not able to assess the stone-free rate at 3 months or one year after the primary intervention because of the patients’ lack of compliance. Therefore, the long-term benefits of using US guidance in MPCNL, such as the stone free-rate after 6 months and 1 year and 2nd look rates, were not addressed. Moreover, the sample size of the present study was small, with 67 patients in each group; therefore, further investigations of the long-term effects in a large sample size are recommended.
CONCLUSIONS

US-guided Chinese MPCNL is a safe and effective procedure for the management of staghorn stones with the advantages of reduced radiation exposure, shorter operative times, and higher stone-free rates than fluoroscopy-guided MPCNL. In addition, the US-guided procedure demonstrates practical value in searching for residual stones with saline instillation.

COMPLIANCE WITH ETHICAL STANDARDS

Conflict of Interest: All authors declared no conflicts of interest.

Ethical approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent: Informed consent was obtained from all individual participants included in the study.

REFERENCES


Cite this article