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ORIGINAL ARTICLE

# Clinical application of super-mini PCNL (SMP) in the treatment of upper urinary tract stones under ultrasound guidance

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## Abstract

**Purpose** To present the safety and efficacy of totally ultrasonography-guided Super-mini percutaneous nephrolithotomy (SMP) in the treatment of upper urinary tract stones both in children and adults.

**Patients and methods** We carried out SMP in 104 patients (including 48 children and 56 adults) with upper urinary tract stones between June 2015 and February 2017. All steps of renal access were performed by ultrasonography. The lithotripsy was performed using either Holmium laser or pneumatic lithotripter. Perioperative and postoperative parameters along with operative data were recorded in detail.

**Results** The mean age of children and adult patients were $4.4 \pm 3.6$ and $44.3 \pm 15.7$ years old, respectively. The stone burden was comparable for both groups ($1.72 \pm 0.66$ vs $1.74 \pm 0.56$ cm, $p = 0.852$). Mean operation time was not significant different between two groups ($p = 0.052$), while the mean haemoglobin drop in children was much lower in adult patients ($6.3 \pm 6.9$ vs $10.9 \pm 8.69$, $p = 0.004$). Both groups had similar SFRs in postoperative 1 day and at 1-month follow-up ($p = 1.000$, $p = 0.912$). Mean hospital stay of children and adult patients was $2.3 \pm 0.8$ and $2.2 \pm 0.76$ days ($p = 0.484$). The total complication rate was significantly lower in two groups ($p = 1.000$); none of the patients required blood transfusion.

**Conclusions** Ultrasonography-guided SMP was a safe and effective treatment option for moderate-sized upper urinary tract stones, and has the advantage of preventing radiation hazard, especially for pediatric stone patients.

**Keywords** Kidney stones · Ultrasound · Complications · SMP

## Introduction

Percutaneous nephrolithotomy (PCNL) has become an established and successful procedure for staghorn stones and large renal stones. During the whole process of PCNL, renal access is a major step. Traditionally, puncture during PCNL is carried out under the guidance of fluoroscopy; while, exposure to radiation is an ongoing concern for the urologists, surgical assistants, nurses and patients.

According to International Commission of Radiological Protection (ICRP 60) report, recommended doses for radiation workers per year are 20 mSv to the whole body [1]. It is reported that the mean fluoroscopy time for PCNL examination was 12 uSv to body [2]. Despite this, the radiation-induced cancer is a stochastic effect that may be induced at any not involved with threshold dose [3]. Of children with renal calculi, up to 44% pediatric patients have metabolic disturbances and anatomical abnormalities which may lead to recurrence in older age [4]; thus, pediatric stone patients may subject to repeated radiation exposure during interventional procedures such as PCNL, URL, ESWL.

With the increase in concern for radiation exposure, alternative radiation-free imaging modalities can be used to minimize the radiation exposure in patients with urinary stone disease [5]. Ultrasonography (US) is the most popular radiation-free imaging method used for the diagnosis or

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follow-up of nephrolithiasis patients, especially for children. In recent years, a growing number of US-guide PCNL has been used alone or complementarily with fluoroscopy in adults to minimize radiation exposure [6–8]. Moreover, results of US-guided PCNL in adults from many studies have shown the similar success and complication rates with fluoroscopy [9–11].

We have recently introduced super-mini percutaneous nephrolithotomy (SMP) as a novel miniaturized-PCNL technique in the management of renal stone disease. According to our experience, SMP is feasible in both adult and pediatric patients, however, the majority of our previous SMP were guided by fluoroscopy, no US-guided SMP have been reported. In the present study, we present the results of totally US-guided SMP in both adult and pediatric patients. To our best knowledge, this is the first report of US-guided SMP in those two populations.

## Patients and methods

### Patients

We retrospectively reviewed the files of 48 children (under age 14 years) and 56 adult stone patients who had undergone SPM between June 2015 and February 2017. Patients with upper urinary tract stone diameter < 3.5 cm who agreed to undergo SMP were eligible for the study. For pediatric patients, the inclusion criteria for our study were: (1) children with stones resistant to and/or requiring multiple sessions for SWL and RIRS treatment, (2) stone diameter larger than 3.5 cm, or (3) those parents who preferred SMP regardless of stone size. Exclusion criteria were patients who underwent other simultaneous surgical procedures, pregnant at the time of surgery, renal malformation, and patients with inadequate correction of coagulopathy pre-operatively.

Both intravenous pyelogram (IVP) and non-contrast CT were performed preoperatively in all patients enrolled in our study. Stone size was measured by the maximum length of the stone. In the case of multiple stones, the size was achieved using the summation of maximum lengths of all individual stones. All patients with positive preoperative urine cultures were treated with appropriate antibiotics according to the culture-antibiogram test results for 3–5 days until the culture results were negative. All patients with negative urine cultures were given a single prophylactic dose of broad spectrum antibiotics 30 min before SMP and on first day post operation.

This study was approved by the Institutional Review Board of the Xinjiang Uyghur Autonomous Region People's Hospital, and informed consent was obtained from each participant.

### SMP techniques

The patient was placed in the lithotomy position under general anesthesia. A 3F or 5F open end ureteric catheter was retrogradely inserted into the collecting system. The patient was then turned prone with appropriate padding placed under the chest and the ipsilateral flank. Ultrasound was used to identify the anatomy of the calyces, the position of the stones and the route of puncture. The selected calix was punctured under ultrasound guidance and a 0.032-inch guidewire was inserted into the collecting system. Nephrostomy tract was established using metal (12 ~ 14 F) suction/evacuation sheath in one step depending on the patient's size and stone burden. After the corresponding size of suction–evacuation sheath was placed, the sheath was connected to the specimen collection bottle via the oblique branch of a plastic connector. A rubber cap, with a central aperture, was placed at the end of the straight branch of the connector. A negative pressure aspirator was attached to the collection bottle. The negative pressure was adjusted to a setting of 150–200 mmHg. The miniature endoscope was inserted into the sheath through the metal connector. The main irrigation was delivered into the working channel of the endoscope sheath using a pump. When the flow of the main irrigation system was insufficient, the auxiliary irrigation system could be used. Holmium: YAG laser with a laser fiber up to 365 μm and/or pneumatic lithotripter with a 0.8 mm probe were/was used for stone fragmentation. The detailed procedure was described in our previous publications [12, 13].

Under continuous suction, tiny stone fragments passed through the space between the scope and the sheath and then exit through the oblique sluice. For larger fragments, the scope was slowly withdrawn to the end of the connector to form an unimpeded channel. Then, the large fragments could pass through the oblique side-port. The negative pressure could be adjusted by either partially or completely occluding the pressure vent. The procedure has been described in detail in our previous papers [12].

After stones were removed, stone-free status was assessed intraoperatively with endoscopic and ultrasonographic visualization. At the end of the procedure, a Double-J stent was placed only in the presence of an obstructing inflammatory ureteral edema, ureteropelvic junction obstruction, or concurrent treatment of ipsilateral ureteral stone with rigid ureteroscope. The sheath was removed, and the wound was either sutured or sealed with absorbable gelatin. For patients with significant bleeding or extravasation, a nephrostomy tube was placed.

Due to the economical and radiation concern, all patients were followed by radiography of the kidneys, ureters and bladder (KUB) and ultrasonography on the postoperative 1 day and 1 month after operation. Any residual fragments less than 4 mm were considered to be clinically insignificant residual fragments (CIRF). A patient was considered to be stone free if there were no residual fragments or with clinically ''insignificant'' residual stones on radiologic evaluation after the procedure. Data collected included demographics, stone data (size, location), operative, and recovery parameters.

## Results

A total of 104 patients were eligible for the study, with 48 pediatric patients and 56 adult patients, respectively (Table 1). The mean age was 4.8 ± 3.6 years in children group and 44.3 ± 15.7 years in adult group. Both groups were comparable in terms of mean stone size (1.72 ± 0.66 vs 1.74 ± 0.56 cm, $p=0.852$), multiple stones (43.8 vs 32.1%, $p=0.223$), and hydronephrosis level ($p=0.230$). Though the positive urine culture rate was higher in pediatric population (22.9 vs 10.7%), the difference between the two groups was not significant ($p=0.019$). (Table 1).

As results shown in Table 2, there were no significant differences in renal access between the two trails ($p=0.461$), and most of the tracts were punctured through middle calyxes, while majority of cases from children group (71.0%) were performed by $F$12 SMP access sheath, almost all the adult patients (92.9%) underwent $F$14 SMP access sheath (Table 2). The mean operation time in adult population was a little longer than that in children group (32.7 ± 16.1 vs 27.1 ± 12.9 min), yet there was no statistically significant difference ($p=0.052$).

Both groups had a comparable postoperative day 1 SFR (95.8 vs 96.4%, $p=1.000$), and 1-month follow-up SFR (98.0 vs 98.2%, $p=0.912$) (Table 3). Three patients from children group needed a second-look procedure, two undergo a repeat SMP, one patient required ureteroscopy. In adult group, repeat SMP was underwent in three patients to further disintegrate the residual fragments, one patient required ureteroscopy and another one

**Table 1** Patient demographics

| Variables | Children ($n$) | Adults ($n$) | $p$ |
|---|---|---|---|
| Patients | 48 | 56 | |
| Male/female | 30/18 | 34/22 | 0.430 |
| Age (year) | 4.8 ± 3.6 | 44.3 ± 15.7 | < 0.0001 |
| BMI (kg/m$^2$) | 17.0 ± 3.3 (10.5–30.6) | 24.2 ± 3.8 (15.3–31.9) | < 0.0001 |
| Mean (SD, range) stone size (cm) | 1.72 ± 0.66 (0.8–3.5) | 1.74 ± 0.56 (0.8–3) | 0.852 |
| Stone feature, $n$ (%) | | | 0.223 |
| Single | 27 (56.2%) | 38 (67.9%) | |
| Multiple | 21 (43.8%) | 18 (32.1%) | |
| Stone opacity | | | 0.062 |
| Opaque | 40 (83.3%) | 53 (94.6%) | |
| Non-opaque | 8 (16.7%) | 3 (5.4%) | |
| Grade of hydronephrosis | | | 0.230 |
| Grade 0 | 19 (39.6%) | 25 (44.6%) | |
| Grade 1 | 20 (41.6%) | 19 (33.9%) | |
| Grade 2 | 9 (18.8%) | 8 (14.3%) | |
| Grade 3 | 0 | 4 (7.1%) | |
| Positive preoperative urine culture | 11 (22.9%) | 6 (10.7%) | 0.093 |

**Table 2** Operative outcome of US-guided SMP in pediatric and adult patients

| Variables | Children ($n=48$) | Adults ($n=56$) | $p$ |
|---|---|---|---|
| Site of puncture | | | 0.461 |
| Upper calyx | 12 (25%) | 9 (16.1%) | |
| Middle calyx | 34 (70.8%) | 43 (76.8%) | |
| Lower calyx | 2 (4.2%) | 4 (7.1%) | |
| Access sheath size | | | < 0.0001 |
| $F$12 | 34 (71.0%) | 4 (7.1%) | |
| $F$14 | 14 (29.0%) | 52 (92.9%) | |
| Duration of surgery (min) | 27.1 ± 12.9 (6–56) | 32.7 ± 16.1 (7–80) | 0.052 |

**Table 3** Stone outcome of US-guided SMP in pediatric and adult patients

| Variables | Children ($n=48$) | Adults ($n=56$) | |
|---|---|---|---|
| Stone-free status | | | |
| Initial SFR | 46 (95.8%) | 54 (96.4%) | 1.0000 |
| Final SFR at 1 month | 47 (98.0%) | 55 (98.2%) | 0.912 |
| Need for second-look procedure | | | 0.887 |
| No | 45 | 51 | |
| Yes | 3 (6.3%) | 5 (8.9%) | |
| Repeat SMP | 2 | 3 | |
| Ureteroscopy | 1 | 1 | |
| SWL | 0 | 1 | |
| Total tubeless | 41 (85.4%) | 52 (92.9%) | 0.219 |
| DJ-stent | 7 (14.6%) | 4 (7.1%) | |
| Mean postoperative hospital stay (d) | 2.3 ± 0.8 (1–4) | 2.2 ± 0.8 (1–5) | 0.484 |
| Mean haemoglobin drop (g/L) | 6.3 ± 6.9 (0–35) | 10.9 ± 8.7 (0–33) | 0.004 |
| Significant complications | 4 (8.3%) | 4 (7.1%) | 1.0000 |
| Clavien Grade I | | | |
| Fever (> 38.5 °C) | 2 (4.2%) | 2 (3.6%) | |
| Pain | 1 (2.1%) | 0 | |
| Clavien Grade II | 0 | 1 | |
| Blood transfusion | 0 | 0 | |
| Perforation | 2 (4.2%) | 1 (1.8%) | |
| Extravasation | 0 | 0 | |
| Urine leakage | 0 | 1 (1.8%) | |
| Clavien Grade III | 0 | 0 | |

had SWL. Total tubeless (no nephrostomy tube and JJ stent) was applied in 41 (85.4%) children and 52 (92.9%) adult patients. In pediatric group, 7 children (14.6%) had a double-J stent placed for 4–6 weeks due to the following reasons: suspicious pelvis injury in three, significant pyelocaliceal blood clots in two, and two cases for minor pelvis perforation. In adult group, 4 (7.1%) had a DJ-stents placed for 4 weeks due to for minor pelvis perforation, urine leakage, and significant residual stones. No statistically significant differences of mean postoperative hospital stay were observed between the two groups (2.3 ± 0.8 vs 2.2 ± 0.8 days, $p = 0.484$). However, mean haemoglobin drop in children group was lower than adult group (6.3 ± 6.9 vs 10.9 ± 8.7 g/L), and the difference was statistically significant ($p = 0.004$). The overall complications rate between two groups was similar (8.3% vs 7.1%, $p = 1.000$). One child developed renal colic after the operation, which was resolved by conservative management in 2 days. 2 (4.2%) patients had a postoperative fever and recovered after culture sensitive antibiotic injection. The most common complication in adult group was fever that occurred in 2 (3.6%) patients who required additional antibiotic management.

## Discussion

Improvements in technology and growing experience have dramatically changed the concepts of urolithiasis management in the last two decades [14]. Though, standard PCNL remains the first treatment of choice for renal stones greater than 2 cm in diameter, the introduction of miniaturized-PCNL techniques such as Miniperc, Microperc, and Ultraminiperc has further expanded the indications of PCNL and provided an alternative treatment option for management of small-size renal stones [15, 16]. The SMP system was designed with an innovatively designed miniature 7 Fr nephroscope and a modified metal 12–14 Fr access sheath [13]. Our previous experience has shown that SMP technique could be a safe and effective alternative for the management of both adult and pediatric kidney stones [12, 13, 17]. While, in our previous works, most of the SMP procedures were performed in a fluoroscopy-guided fashion. Radiologic exposure has been a major concern about this procedure, especially when performed in pediatric patients.

Fluoroscopy-guided PCNL exposes both patients and operators to an amount of ionizing radiation which may cause genetic mutation and cancer, and the severity of the effect increases with dose [18]. This issue should be more concerned in children who have undergone radiographic examination, as children have longer anticipated life spans and are three–ten times more radiosensitive than adults [19]. Current pediatric computed tomography (CT) scan utilization alone is predicted to result in an additional 4800 future malignancies per year [20]. The International Commission on Radiological Protection (ICRP) set a safe radiation exposure limit to 50 mSv any single year or 20 mSv per year during a 5-year period [21]; while, according to a multicenter retrospective study, nearly 20% adult patients who underwent PCNL received radiation exposure greater than 50 mSv [22]. Since children is often associated with anatomical and metabolic abnormalities, the risk of complications and recurrences is high; therefore, pediatric patients are clearly more prone to radiation-induced negative effects compared to adult patients. Thus, it is important to control and minimize radiation exposure in this population. Based on the limited reports in the literature on pediatric patients, time needed to establish renal access was 4.5–11.7 min [23–25]. Using the published average effective dose of 0.024 mSv/s for fluoroscopy, the estimated median effective dose for PCNL is 6.48–16.8 mSv. In all cases of this study, we did not use fluoroscopy in any steps during PCNL, and all the steps were performed by ultrasonography.

Considering the relatively small size and fragility of the pediatric renal unit of children, use of small caliber instruments is especially important for this patient population to reduce the trauma as much as possible. Though several studies performed pediatric PCNL procedure by adult-size instruments and reported no significant differences in outcomes [26, 27], accumulating evidences have suggested that the size of the tract is significantly correlated with the morbidity of PCNL in children [23, 28]. A recent study by Celik et al. also showed that using smaller sized catheters in pediatric patients can reduce the risk of bleeding [29]. One might predict that pediatric patients are more sensitive to hemoglobin decrease when compared with adults, while the hemoglobin drop in adult group was significantly higher than the pediatric group (6.3 vs 10.9 g/L). One possible explanation for our finding is that a higher ratio of $F12$ SMP renal access sheath was used in the children patients (71.0%), which contributed to a low risk of bleeding. In adult population, $F12$ access sheath was only 7.1% of patients.

Recently, there are several studies presenting feasibility and safety of microperc in pediatric population. It was considered with comparable SFRs with miniperc ($F12$–$F20$) and with the advantage of providing a smaller tract size. The main advantage of microperc in pediatric patient is the low risk of bleeding. In the study by Desai et al. [30], the mean hemoglobin decrease was calculated as 1.4 g/dL. In another study, the mean hemoglobin decrease was $0.1 \pm 0.3$ mg/dL for moderate-size renal stones [31]. Bodakçi et al. [32] reported in his study that microperc was carried out in 25 pediatric patients and the average hemoglobin decrease was $0.46 \pm 0.63$ g/dL. In our study, the mean hemoglobin decrease ($0.63 \pm 0.69$ g/dL) was similar to the results from microperc trails. While, one limitation of microperc is its inability to remove the stones from the kidney. This is also the disadvantage for the clearance of the fragments. In the pediatric population, it is highly recommended to learn the stone composition in addition to performing a metabolic evaluation. Another issue needed to be considered is the increased intrarenal pressure. Tepeler et al. reported high intrarenal pelvic pressure in patients who had undergone the microperc operation compared with standard PCNL [33]. This fact may contribute a possible irrigant extravasations and renal colic in the postoperative period [34]. In SMP procedure, with continuous negative pressure aspiration through the SMP suction sheath, stone fragments were actively removed and no forceps were required to extract fragments [13, 17]. The intrarenal pressure was barely over 25 mmHg during the SMP procedure. Ultramini-PNL (UMP) is also a new treatment modality which seems to be promising for the management of middle-sized stones [35]. While, to data, only one study of UMP technique in pediatric patients has been reported [35]; its role and indications remain to be seen in larger prospective studies in exclusive pediatric populations.

Clearance rate and operative time are an important restrictive factor for minimally invasive surgeries. A smaller field of vision and the longer fragmentation time needed to extract the stone fragments through a small-caliber tract might prolong the operative time and compromise SFRs. In the present work, the initial stone-free rates in adult and children groups were 95.8 and 96.4%, respectively. This result is comparable to the results obtained from the previous fluoroscopic-guided pediatric SMP population and other pediatric PCNL series [13, 32, 35–39] (Table 4). In addition, our results are similar to those previous studies in terms of hemoglobin drop and complications rate. Among those studies, the mean operation times were 39.4–75 min; in our present trail, US-guided SMP seems to take advantage of operation time, which was 27.1 min in pediatric patients. The radiation-free nature of ultrasound allows for continuous monitoring of the collecting system in a 3-dimensional orientation throughout the entire puncture procedure, during which the tissues between the skin and kidney can be identified; it will help to achieve a higher success rate of first puncture, and it is quick to obtain the access to the targeted calyx especially for experienced operators. Combined with the shorter access time, the high success rate of first puncture also contributed to the less blood loss and shorter operation time [6, 8, 40, 41]. In addition, the visualization of non-opaque or semi-opaque stones that are not visible with fluoroscopy

**Table 4** The summary of the studies presenting the outcomes of miniaturized-PCNL procedure in pediatric patients

| Study | *N* | Technique | Mean age (years) | Stone size (mm) | Hemoglobin drop (g/dL) | Operation time (min) | Success rate (%) | Complication rate (%) | Total tubeless rate (%) | Hospitalization (days) |
|---|---|---|---|---|---|---|---|---|---|---|
| Dede et al. [35] | 39 | UMP | 5.8 | 20.4 | 0.9 | 56 | 87.1 | 15.3 | 61.5 | 2.8 |
| Dağgülli et al. [34] | 40 | Microperc | 6.3 | 16.5 | 0.7 | 75 | 80 | 17.5 | 72.5 | 3.8 |
| Karatag et al. [36] | 63 | Miniperc | 9.3 | 14.8 | 1.9 | 68.9 | 93.6 | 12.6 | NA | 2.9 |
| Dundar et al. [37] | 27 | Miniperc | 9.5 | 13.4 | 1.1 | 74.1 | 92.6 | NA | NA | 4.0 |
| Bodakçi et al. [32] | 25 | Microperc | 4.1 | 13.5 | 0.5 | 51.5 | 92.0 | 12.0 | 80.0 | 3.1 |
| Silay et al. [38] | 19 | Microperc | 7.5 | 14.8 | 1.0 | 72.5 | 89.5 | 15.8 | 78.9 | 1.8 |
| Hatipoglu et al. [39] | 37 | Microperc | 8.4 | 14.8 | 0.9 | 63.6 | 89.2 | 21.6 | NA | 2.1 |
| Liu et al. [13] | 111 | SMP | 3.9 | 14.0 | 1.0 | 39.4 | 90.1 | 15.3 | 85.6 | 2.7 |

*UMP* ultra-mini-percutaneous nephrolithotomy, *Microperc* micro-percutaneous nephrolithotomy, *SMP* super-mini-percutaneous nephrolithotomy

is another advantage of US, which may contribute to higher clearance during the procedure.

Some researchers considered US as a poor diagnostic tool for detecting retained calculi compared with other imaging modalities [42]. Osman et al. reported that the sensitivity for detecting significant residual stones was 58.3% for KUB and 41.6% for ultrasound [42]. In the present study, to reduce the radiation dose, residual stone was detected by ultrasound-combined SMP telescope. Since SMP has a 7F diameter nephroscope and the kidney of child was more flexiable than adult, more calyxes can be reached by SMP, thus help to examine the stone-free status in the end of the surgical procedure. The final success rate was evaluated by KUB and US 1 month after surgery; residual stones larger than 4 mm will be easy to detect. Another problem of the ultrasonography is poor imaging of the renal anatomy in obese patients and in patients with non-dilated collecting systems [43]. Though it has previously been shown that ultrasonography-guided PCNL is equivalent to or even sometimes better than fluoroscopy-guided PCNL in terms of stone-free rate [44–46], bleeding [46], and complications [45], some urologists concerned that performing ultrasonography guided PCNL in pediatric patients requires a very experienced hand. In one study by Ng FC et al. [47], they pointed that the learning curve for US-guided access PCNL (USGA–PCNL) is minimal compared to conventional fluoroscopy-guided access PCNL, and there was also no statistical significance in terms of the grades of surgeon performing the surgery in USGA–PCNL ($p = 0.135$). Desai also suggested that the use of ultrasound puncture guide can be considered as a start to increase the surgeon's confidence [11].

In terms of safety, it is advisable to perform a percutaneous renal procedure with the availability of an X-ray equipment in the operating room; this is especially important for unexperienced urologist. For patients with minimal hydronephrosis, upper pole access or complex stones, the combined ultrasonographic and fluoroscopic guidance approach for renal access has been advocated.

One limitation of our study was the small number of cases. Therefore, larger prospective series are needed to corroborate these findings and to make them generalizable to a wider population. Despite this, we provided the initial data on the use of ultrasonography for SMP in both children adults and demonstrated its safety and effectiveness. For pediatric patients, a smaller renal access sheath ($F12$) can be performed in most of the cases, which would contribute a lower risk of bleeding and shorter hospital stay.

## Conclusions

This study demonstrates for the first time that US-guided SMP is safe and effective for the management of moderate-sized upper urinary tract stones in both children and adult patients. Eliminating fluoroscopy guidance during the procedure significantly will definitely benefit patients for decreasing radiation hazards, especially for children population. However, US-guided pediatric SMP requires more experience just as do other surgical procedures performed in children.

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## Compliance with ethical standards

**Conflict of interest** The authors declare no conflict of interest.

**Ethical approval** All procedures performed in studies involving human participants were obtained from the institutional Ethics committee of The Xinjiang Uyghur Autonomous Region People's Hospital, Xinjiang, China.

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