Percutaneous nephrostomies-
Planning for an Optimal Access,
Complications, Follow-up and
Outcome

by

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Abstract

Percutaneous nephrostomy (PCN) is a well-established intervention performed to divert urine from the collecting system in cases of ureteric obstruction or as a prelude to interventional procedures such as stent placement or percutaneous nephrolithotripsy (PCNL). The primary aim of this thesis is to enhance planning for an optimal insertion of a percutaneous nephrostomy and to develop a technique to optimise the certainty of reaching a specific target in the kidney. Additional aims were to investigate the complications and long-term management in PCN patients, to study the follow-up and outcome in patients with PCN treatment, and to increase accuracy in CT-guided punctures.

To enhance planning for an optimal insertion of PCN prior to PCNL, biomodels from CT data were performed. Eight patients with complex urinary calculi in the collecting system were selected. Multislice CT of the kidney was performed and the CT data were transformed into a format compatible with producing a biomodel. An exact plastic replica of the pelvocalyceal system and the calculi were created. The biomodels enhanced the ability to visualise a patient’s unique structures before surgery, which aided the planning of endourological procedures.

PCNL is an essential procedure for treating complex urinary calculi. A subcostal approach is preferred to avoid laceration to the lung and pleura. However, a supracostal approach is often preferable, as it gives a better passage to the renal pelvis and calculi. The nature and frequency of complications after supra- versus subcostal punctures were studied in 85 patients treated with PCNL. In 63 patients, a subcostal track was established; in the remaining 22, a supracostal puncture was chosen. The main difference in preoperative complications was the higher number of patients in the supracostal group complaining of respiratory correlated pain 7 (32%). In the subcostal group, this was 3 (5%). In the supracostal group, 2 patients developed pneumothorax.

401 patients were reviewed retrospectively regarding underlying disease, subsequent management and complications of PCN treatment. The number of major complications in the whole group was 4%. Minor complications were recorded in 38%, urinary tract infection being the most common minor complication. 151 of the patients suffered from malignancy. The majority (84) of the patients with malignant disease died with the catheter. The median survival time of the patients with malignacies was 255 days and the median catheterisation time was 62 days.

In order to increase accuracy when performing CT guided punctures, a new puncture guide was evaluated. In 15 of the 17 patients puncture was successful on the first attempt. The benefits of the puncture guide were the artefact from the needle guide pointing at the target to indicate the puncture path and the needle support enhancing an accurate puncture.

Key words: Percutaneous nephrostomy, percutaneous nephrolithotripsy, complications, puncture technique, CT guidance.
TO MY PARENTS
LIST OF PAPERS

The thesis is based on the following papers:

I. Radecka E, Brehmer M, Holmgren K, Magnusson A.
   Complications associated with percutaneous nephrolithotripsy: supra- versus subcostal access.
   A retrospective study.

II. Radecka E, Magnusson A.
    Complications associated with percutaneous nephrostomies. A retrospective study.

III. Magnusson A, Radecka E, Lönnemark M, Raland H.
    CT-Guided punctures using a new guidance device.
    Accepted for publication in Acta Radiol.

IV. Radecka E, Brehmer M, Holmgren K, Palm G, Magnusson P, Magnusson A.
    Pelvo-calyceal biomodelling as an aid to achieving optimal access in Percutaneous nephrolithotomy.
    Submitted to Br J Urol.

V. Radecka E, Magnusson M, Magnusson A.
    Survival time and period of catheterisation in patients treated with percutaneous nephrostomy for urinary obstruction due to malignancy.
    Submitted to Acta Radiol.
**ABBREVIATIONS**

PCN  Percutaneous nephrostomy
PCNL Percutaneous nephrolithotripsy
CT  Computed tomography
3D Three-dimensional
F  French
G  Gauge
ESWL Extracorporeal shock wave lithotripsy
IVU Intravenous urography
CAD Computed aided design
US Ultrasound
PT Prothrombin time
INTRODUCTION

Background

Percutaneous nephrostomy (PCN) is one of the most common interventional procedures, performed to divert urine from an obstructed collecting system or as a prelude to interventional procedures such as stent placement, endoscopy or percutaneous nephrolithotomy (PCNL).

In 1955, Goodwin (1) described the technique for temporary drainage of the renal pelvis. Ten years later, Bartley described a technique for the application of a permanent drainage (2). Bartley used a modified Seldinger technique and relieved the pressure on the renal pelvis using an angiography catheter. The procedure first became generally accepted when Almgård and Fernström (3) described a technique for the application of nephrostomy using a Foley catheter. Almgård and Fernström used a dilatation technique in which the nephrostomy channel was dilated by gradually increasing the size of the catheter. The technique was time-consuming, and it could take a week from the first puncture until the Foley catheter was in place. The time required was reduced considerably when Lindgren and Hemmingsson introduced the coaxial dilatation technique (4).

In 1974 the first ultrasound-guided percutaneous nephrostomy was reported (5). The Cope loop catheter, which has a distal loop that is reformed in the renal pelvis with a loop shape, was introduced by Cope in 1980 (6).

Anatomy

The kidney is a retroperitoneal organ covered by a fibrous capsule. The exact position of the kidneys varies in different individuals and is altered by respiration and the position of the body. The upper pole of the kidney is more posterior and medial than the lower pole. Of special interest is the relation of the diaphragm to the upper poles of the kidney. The posterior part of the diaphragm arises from the tip of the 10th to the 12th rib posteriorly. The caudal border of the lung normally lies at the level of the 10th thoracic vertebrae posteriorly, but may vary with the patients age, constitution, posture, inspiration and lung disease (7).

Every human being has a unique renal pelvis, with a wide range of individual anatomic variations. According to Löfgren (8) the typical kidney has 7 pairs of papillae and calyces, each with a ventral and dorsal part. In the polar regions, especially in the cranial, fusion of the papillae and reduced numbers of calyces is common.

Normally the lateral margin of the kidney is rotated posteriorly, according to Kaye and Reinke (9). The frontal plane of the right kidney is, on average, rotated 33° to the frontal plane of the body (range 12–50°). In the left kidney, the average is 23° (range 9–45°). According to Geterud (10) the angle between the axis of the renal pelvis and the vertebral column was –16° to 60° (mean 10°) on the right side. A negative angle means that the cranial part of the pelvis is ventral to the caudal. On the left side, the axis varied between –8° to 33° (mean 9°).

The vascular supply of the kidney is about 20 times greater than that of any other organ (7). The renal artery arises from the aorta, and about 70% of all kidneys are supplied by a single artery (11). In the renal sinus, the artery is situated dorsal to the vein and ventral to the renal pelvis. The kidney is divided into five segments, each segment being supplied by its own branch of the renal artery. The segmental arteries usually branch near each calyx major to form paired interlobular arteries, which pass up the sides of the calyces and become interlobar arteries. These vessels course adjacent to the cortical Bertini septa between renal pyramids before penetrating the renal parenchyma as arcuate arteries.
In most patients there is a zone of relative avascularity known as the “Brödel bloodless line of incision” in which no large-calibre renal arterial branches are present (12). This occurs at the posterolateral aspect of the kidney, near the junction of the anterior two-thirds and the posterior third of the renal parenchyma. To avoid major branches of the renal artery, this area is ideal for puncturing to obtain access to the collecting system. Preferably a minor calyx should be punctured from a 20–30° posterolateral oblique approach. The calyx should be punctured through the papilla in order to avoid the larger arterial branches. Usually the posterior calyces are oriented so that the long axis points through the avascular zone of the kidney (13).

The renal veins from the posterior part of the kidney cross over the neck of the calyces and join the anterior veins and proceed to the inferior vena cava (14).

**Indications for percutaneous nephrostomy**

- Drainage of the collecting system is the most common indication for PCN treatment. Intrinsic or extrinsic factors such as stones, malignancy, pregnancy or iatrogenic disorders may cause urinary tract obstruction. A severe complication of urinary tract obstruction is pyonephrosis or infected hydronephrosis. Urinary tract stones are the source of obstruction in more than 50% of these cases, and these patients with pyonephrosis need an acute PCN due to the high risk of Gram-negative sepsis.
- PCN may be needed to divert urine after iatrogenic injuries, urinary leakage or fistulas. The PCN may then be combined with a ureteral stent for complete urinary diversion.
- Access to the collecting system is needed as a prelude to further interventional procedures and endoscopy. These interventional procedures include PCNL, ureteral stent placement when the retrograde approach is impossible, foreign body retrieval such as migrating stents, or as a way to deliver medications such as chemolysis of renal calculi. Urodynamic studies (i.e Whitaker test) are possible via the route established by PCN.

Relative contraindications for PCN are uncorrectable severe coagulopathy and terminal illness.
Percutaneous nephrostomy insertion

Various techniques, instruments and catheters have been used to establish a PCN in order to perform a secure and accurate puncture. Imaging by ultrasound, fluoroscopy with or without intravenous contrast and, more recently, computed tomography (CT) (15) have been used for the initial puncture. A number of nephrostomy sets are available to provide instruments and catheters.

For long-term drainage, the distal portion of the catheter may be preshaped to acquire a pigtail loop or a tulip-shaped widening after being introduced into the renal pelvis. There are many variations of these two basic types of catheters. The Malecot or tulip type catheter is usually used when there is a very narrow renal pelvis, which will not accommodate the larger loop fixation, or when there are calculi filling out the renal calyx or pelvis (16).

The Cope loop catheter has a distal loop that is reformed in the renal pelvis. The loop-shape is then locked by pulling and fixating a built-in monofilament string to prevent the loop from opening (6). The retention properties are excellent, but difficulties can arise when trying to reform the catheter in a narrow renal pelvis.

Alternative methods to divert urine from the collecting system include a double J-stent inserted by antegrade or retrograde route and thermoexpandable ureteric stents (Fig. 1).

Fig. 1.
Alternative methods to divert urine from the collecting system include double J-stent inserted by antegrade or retrograde route and thermoexpandable ureteric stents.
a) Plain radiograph of the abdomen revealing a right-sided double J-stent.
b) Antegrade pyelography showing a left-sided thermoexpandable ureteric stent.
Complications to percutaneous nephrostomies

Even when the procedure is performed by experienced physicians, major complications – such as haemorrhage, sepsis and injuries to adjacent organs causing pneumothorax, hemothorax and bowel injury – may occur in as many as 4% (1, 17) of PCN procedures.

To avoid haemorrhage, abnormal prothrombin time (PT) and platelet counts should be corrected with fresh frozen plasma or platelets before the procedure.

When puncturing, care should be taken to enter the distal part of the calyx, which involves a lesser risk of arterial injury compared with a central, calyx major puncture. Gross hematuria commonly drains through the catheter and disappears after a couple of days, but embolisation or blood transfusions may be indicated when conservative treatment is not enough.

Because of the close anatomic relationship between the upper pole of the kidney and the pleura and lung, the incidence of thoracic complications such as pneumothorax and hemothorax increases when performing a supracostal puncture above the 12th rib (18). However, a supracostal puncture may be necessary to obtain better access to the lower pole of the kidney and ureter when performing further interventions (Fig. 2).

![Diagram of percutaneous nephrostomy procedure]

Fig. 2.
A subcostal puncture (needle A) results in an acute angle between track and the longitudinal axis of the collecting system. A more favorable track may be established by direct puncture of an upper calyx (needle B).
(Colour print available in the supplement, page 40.)
Septicaemia and infectious complications due to PCN insertion will be influenced by the administration of prophylactic antibiotics. Cochran et al. reported that, in their high-risk group, 50% developed evidence of sepsis without antibiotics compared with only 9% when antibiotic cover was provided (19). Another factor that reduces the incidence of septicaemia is the avoidance of delay when performing the PCN. In cases of obstruction, partial decompression of the system is necessary before injecting the contrast, causing an overdistended collecting system and forcing infected urine into the urinary sinus or interstitial tissue. Perinephric abscesses may occur as an infectious complication; these may require their own percutaneous drainage. Due to the retroperitoneal position of the kidney, an infection may involve the whole retroperitoneum.

Minor complications of PCN include urinary tract infections, loss of catheter, catheter displacement/oclusion or urinary leakage.

Catheter occlusion by debris or clots should be irrigated by flushing with normal saline or a guidewire passed down the catheter to dislodge the obstruction. Catheter obstruction by debris is less likely to occur if catheters are changed on a regular basis.

Management of complex renal stones

Before the early 1980s, most renal and ureteric stones with an indication for active stone removal were treated by open surgery (20, 21). In the last 20 years, the treatment of urolithiasis has changed completely. A report on the first patients in whom kidney stones were extracted percutaneously was published in 1976 (22). The clinical introduction of extracorporeal shock wave lithotripsy (ESWL) was reported in 1982 (23). Three years later, the combination of ureteroscopy and ESWL was described (24). The following year, the initial experience with a pulsed dye laser for ureteric calculi was reported (25).

Currently, a multimodal approach is used to minimise the morbidity of treatment and optimise the long-term results. This may include:

- ESWL with or without double J-stent.
- PCNL.
- Combination of PCNL and ESWL.
- Retrograde ureteroscopic stone disintegration using holmium laser or pneumatic lithotripsy.
- Open surgery.

The size, site and shape of the stone influence the decision on how to deal with it. Spontaneous stone passage may be expected in up to 80% of patients with stones no larger than 4 mm. For stones with a diameter exceeding 7 mm, the chance of spontaneous passage is low (26). Stone removal is usually indicated for stones with a diameter exceeding 6–7 mm, and is strongly recommended in patients with the following (27):

- Persistent pain despite adequate medication.
- Persistent obstruction with impaired renal function.
- Urinary tract infection.
- Risk of pyonephrosis or urosepsis.
- Bilateral obstruction.
- Obstructing calculus in a solitary functioning kidney.

ESWL as a monotherapy is usually used in patients with minor stone burden and patients with enhanced risk (arteriosclerosis, respiratory problems). Patients with major stone burden, slightly opaque or shock-wave resistant calculi are candidates for PCNL alone. The combination of ESWL and PCNL is used in cases where the calculi cannot be reached with the nephroscope. Additional ESWL may be used to disintegrate remaining fragments after incomplete PCNL.
Optimal route in percutaneous nephrolithotripsy

To avoid injuries to the lung and pleura, a lower pole calyx is the most secure and common access route when performing PCN. However, puncturing the upper calyx is a more direct route to the long axis of the kidney, giving a smoother passage to interventions in the lower pole or ureter. Therefore, an upper or middle calyx puncture is sometimes chosen when performing PCNL or inserting ureteral stents. When performing these punctures, it is of extra interest to plan and image the projected track to avoid complications such as pneumo- or hydrothorax.

Optimal imaging is the first step in planning for a good approach to the stones in PCNL. For many years, intravenous urography (IVU) has been used to depict kidney stones. Stones with low attenuation value may, however, not be depicted with IVU and, in recent years, CT has been used to confirm kidney stones. Due to the complex three-dimensional anatomy of the collecting system, there may be difficulties in visualising the anatomy. A further step for better understanding and visualisation of the anatomy is three-dimensional CT reconstructions. However, the complexity of the CT technique, its output as data rather than real images and lack of computer skills and time have limited widespread application.

Because of the potential risk of damage to the pleura, lung, spleen or liver, the supracostal approach has been discouraged in PCN placement (28, 29). To reduce complications to a minimum, the use of spiral CT and fluoroscopic guidance have been performed to visualise the planned path (15, 28). Traditionally, CT-guided punctures were performed using freehand technique. However, this technique can be time consuming and often needs a large number of control scans. To simplify CT-guided punctures and to increase accuracy, laser guidance techniques have been developed (30). One drawback with laser guidance has been the difficulty of keeping the needle in the laser beam, which contributes to a slow needle insertion and reduces accuracy. In addition, when performing superficial punctures, there is not enough tissue to support the needle, leading to a deviating needle path.
AIMS OF THE STUDY

Aim for the whole project
The general purpose of this thesis is to develop a technique to optimise the preoperative planning in order to increase the certainty in PCN of reaching the specific target in the kidney and to reduce the number of complications. An additional aim was to investigate the complications, follow-up and outcome of PCN treatment.

The specific aims
1. To enhance planning for the insertion of a percutaneous nephrostomy to achieve an optimal access for PCNL (Paper IV).
2. To investigate the incidence of complications in patients treated with percutaneous nephrostomy, and relate these to modality and puncture location (Paper I, II).
3. To study the follow-up and outcome in patients with percutaneous nephrostomy (Paper II, V).
4. To increase accuracy in CT-guided punctures (Paper III).
MATERIAL AND METHODS

Patients
All patients included were referred for treatment with PCN.

Paper I was a study of 85 patients treated with PCN from January 1996 to December 2001 as a prelude to further PCNL. The patients ranged in age from 19 to 93 years (mean 59.8 years). There were 44 females and 41 males.

Paper II was a study of 525 patients who were referred to our department between January 1998 and December 2002 for PCN treatment. Kidney transplanted patients, patients obtaining PCN preceding subsequent intervention and patients who were transferred to other hospitals and therefore lost at follow-up were excluded from further evaluation. 401 patients were reviewed retrospectively. Bilateral PCN was undertaken in 83 patients and 114 had more than one procedure during the five-year observation period. This gave us a total of 569 PCN procedures. Patients’ ages ranged from 19 to 97 (mean 64.1 years). There were 242 men and 159 women. The indications for PCN were: obstruction due to ureteric stone (n=163), malignancy (n=153), benign ureteric stricture (n=40), pyonephrosis (n=26), postoperative leaking anastomoses (n=10), unknown cause (n=6), pregnancy (n=3).

To verify hydronephrosis, urography (n=221), ultrasonography (n=214) or CT (n=134) was performed.

Paper III was a study of 17 patients (15 for biopsy and 2 for drainage) who underwent CT-guided punctures. There were 12 men and 5 women, with a mean age of 57±12 years (range 26–81 years). The anatomic locations of the lesions for biopsy were thorax (n=10) abdomen (n=4) and pelvis (n=3).

Paper IV studies 8 patients with complex urinary calculi who were selected after being referred for PCN prior to PCNL. Mean age was 57.3 (range 28–79 years) and there were 5 men and 3 women.

In Paper V, the patients from Paper II were reviewed and 151 patients with malignancies selected. Two patients from Paper II who suffered from both malignancy and nephrolithiasis were excluded because the main indication for PCN treatment was urolithiasis. The mean age was 73.1 years (range 51–97 years). There were 112 men and 39 women. The underlying malignancies were prostatic malignancy (n=55), urinary bladder malignancy (n=44), gynecological malignancy (n=12), colorectal malignancy (n=16) and other malignancies (n=24).

Data collecting
In Papers I, II and V, the charts were reviewed by the author retrospectively, paying attention to clinical notes on factors such as underlying disease and the further management of complications, procedural notes describing imaging modality for guidance and location of the puncture and further interventions. In Paper I, the patients were divided into two groups, the sub- and supracostal group.

In Paper III, data were collected concerning number of punctures, calculated puncture depth and angle, the final angle of the needle and the angle and the quality of the streak artefact. The measurements were taken by two independent, experienced CT interventionists, one of whom (Observer B) was not involved in the procedures. Measurements, as well as grading of the final needle and streak artefact angles, were taken at a later occasion. The measurements of the final needle angle and streak artefact angle were separated.
Percutaneous nephrostomy planning

In Papers I and IV, the patients were referred for PCN insertion prior to PCNL treatment. In order to achieve optimal access to the stone, the track was planned in advance together with the urologist. As described in Paper IV, CT examination was performed on a Siemens Somatom, Sensation 16 (Siemens AG, Forcheim, Germany), with the patient in prone position to simulate the position during surgery. Cushions under the abdomen served as ureteral compression. CT scans with collimation 0.75 mm were performed and reconstructions with slice thickness of 1.0 mm and slice increment of 0.6 mm were obtained, using 100 kV, 100mAs. When performing the first CT series, no contrast medium was administered. In the second series, performed using the same technique and patient position, contrast medium was administered iv, using Omnipaque 300mg/ml (Amersham Health AB, Solna, Sweden), 1 ml/kg or, if possible, in a nephrostomy tube. When injecting into the nephrostomy tube, 5 ml of Omnipaque 300 mg/ml diluted in 100 ml NaCl was used, of which 20–40 ml was injected. If contrast medium was administered iv 10 mg Furosemide was administered iv 5 minutes prior to the excretory phase. The second CT scan was performed with a delay of 300 seconds in order to perform the CT scans in the excretory phase.

Biomodelling

The data of interest were processed by Mimics 7.30 and Materialise software to transform the raw CT data into a CAD (computed aided design) format acceptable to a biomodelling system (Fig. 3). The CT images in native and excretory phase were matched in the CAD model, and the borders of the CAD model and biomodel were matched parallel to the borders of the CT images, making it easier to orient the biomodel in three dimensions. The CAD modelling was performed by IVF and GP Modellframställning. Prototal AB, Jönköping, Sweden created the biomodels. The 12th rib was included in the biomodels so that the anatomical relationship between the kidney and other organs, such as the pleura and lung, could be identified. This was important because of the increased risk of damaging the lung or pleura when performing a supracostal puncture.

A liquid-bed laser curing system was used to produce the biomodels. An ultraviolet laser beam traced out the given contour of the biomodel and solidified layers of a photosensitive liquid plastic photopolymer resin in a specific depth. When one layer was polymerised, the platform lowered itself with one layer’s thickness and the next layer was then polymerised. A multilayered model resembling the slices of the corresponding CT scans was progressively constructed and the slices fused together, resulting in the final biomodel (Fig. 4).

Percutaneous nephrostomy placement

The nephrostomies were placed under local anaesthesia and antibiotic cover (sulfametaxazol + trimetroprim as a single dose immediately before the procedure). With the patient in prone position, the selected calyx was punctured with a 0.9 needle (Mediplast, Malmö, Sweden). The ultrasound (US) and fluoroscopic guided punctures were performed during breath hold, usually during inspiration.

A 0.46 mm guide wire (Duo Guide, Radi Medical Systems, Uppsala, Sweden) was inserted through the needle and after withdrawal of the needle, a 10F dilator (Tapertip, Radi Medical Systems, Uppsala, Sweden) was introduced over the guide wire. An 8 or 10F nephrostomy catheter (Camlock, William Cook Europé, Bjaevskov, Denmark) was introduced over the guide wire.

When performing CT guided punctures, a helical scanning of the kidney was performed with the patient in prone position. To reduce the risk of puncturing the lung and pleura the examination was performed during expiration.
In Paper I, the patients were further treated with PCNL. The radiologist and the urologist decided together a suitable calyx for puncture. In 63 patients (74%), the track was established subcostally using US (n=49), fluoroscopic (n=12) or CT (n=2) guidance. In 22 patients (26%), a supracostal puncture was performed under CT (n=17), US (n=2) or fluoroscopic (n=3) guidance above the 12th rib. All the CT guided punctures and most of the US and fluoroscopic punctures were performed in the radiology department. The remaining US and fluoroscopic punctures were performed in the operating theatre. The PCN was inserted and PCNL was performed in the operating theatre under general anaesthesia.

In Paper II, access to the pelvo-calyceal system was established using US (n=530), fluoroscopic (n=33) and CT (n=6) guidance.

**Puncture performance**

In Paper III, the patients underwent CT-guided punctures. In 15 cases a biopsy was performed and in two cases a drainage catheter was inserted. All the procedures were performed by two experienced CT interventionists. The 15 biopsies were performed with a 17 G introducer needle (Co- Axial- Introducer Needle, Inter. V, Gainsville, USA). The two punctures for drainage were performed with a 20 G needle (Mediplast, Malmö, Sweden).
Percutaneous nephrolithotripsy performance

After transurethral insertion of an 8 F ureteric catheter, to prevent migration of stone fragments during the operation, the patient was placed in prone position. The track was dilated to 10 mm, and an Amplatz sheath (Amplatz sheath, Boston Scientific Co., Boston, USA) was placed under fluoroscopic guidance.

Fragmentation of the stones was performed with ultrasonic lithotripsy, laser, or both. The stones were removed through a rigid nephroscope using grasping forceps. After stone extraction, a PCN tube (10.2 - 16 F) was inserted to stent the track. The PCN remained in position until antegrade pyelography, performed 1–5 days postoperatively, showed satisfactory drainage down the ureter without leakage or remaining fragments necessitating further treatment.

CT-guided puncture devices

In Papers I and II, a stereotactic guidance device (CT-Guide, Bard Limited, Covington, UK) (31) or a laser guide (Simplicity CT Medrad, Oslo, Norway) was used when performing CT-guided punctures. In Paper III, all punctures were performed with the laser guide. The punctures were always preceded by a diagnostic CT examination. Based on that examination, positioning of the patient and the approximate entry point was decided. A radiopaque sterile indicator grid (Seegrid, Radi Medical Systems, Uppsala, Sweden) was placed over the patient’s entry area and fixed to the skin. Helical CT scanning (Siemens Sensation 16) of the kidney was performed in order to select the appropriate calyx and a safe path for the needle was selected. The desired depth and angle of the needle insertion was calculated on the screen using the software for distance measurements. The puncture angle was transferred to the guidance device while puncture depth was set on the needle. Using the CT scanner’s slice indicator and the grid, the entry point was marked on the skin and the patient was brought out of the gantry. After injection of lo-
cal anaesthetics, an incision of the skin over the entry point was made and the guidance device was positioned. The selected calyx was punctured using the laser guide and the guidance device. The position of the needle was verified with a new helical CT scan. If the tip was in correct position the patient was moved out of the gantry and the nephrostomy was inserted under fluoroscopic guidance. The laser guide is described in detail by Brabrand K et al. (30).

The puncture guide
The puncture guide consists of three parts: a baseplate, a tubular needle guide and a locking ring (Fig. 5). In the centre of the baseplate, there is a semi-sphere with a bore extending from the top of the semi-sphere to the bottom of the baseplate. The needle guide can be angled ±30° in any direction and, as the centre of the semi-sphere of the base plate constitutes the rotational centre of the needle guide, the latter will always be directed towards the same point (the entry point). This is independent of angulation (Fig. 6). The metallic tube in the needle guide creates a streak artefact in the image, which constitutes an elongation of the needle guide, indicating the needle path (Fig. 7a).

Fig. 6.
Cross sectional view of the device. The entry point constitutes the rotational centre of the needle guide. (Colour print available in the supplement, page 40.)

Fig. 7.
A 42-year old female with a stone in a horseshoe kidney. CT guided nephrostomy preoperative to percutaneous nephrolithotripsy. a) Streak artefact indicating the needle path to a calyx. b) Final CT scan confirming a correct needle position.
In Paper III, the puncture guide was used as a supplement to the traditional laser guidance device. The length and angle of the path was calculated on the screen using the software for distance measurements. The puncture angle was transferred to the laser guide while puncture depth plus 40 mm (40 mm is the length of the needle guide), was set on the needle. The grid was removed and the laser guide was positioned. The base of the puncture guide was then placed on the entry point and adhered to the skin. The needle guide was assembled to it and positioned in the given angle, guided by the laser beam. When performing a control CT scan, the streak artefact from the needle guide indicated the needle path. The puncture was then performed through the needle guide to the desired depth and a new scan was then performed to check the position of the needle (Fig. 7b). After confirming a correct position, traditional PCN treatment may be obtained using the Seldinger technique.

Statistics

In Papers I and II, data were presented as mean values.

In Paper III, all values were expressed as mean ±1 SD and range.

In paper V, data were presented as median or mean values. The Cox proportional hazard model was used to analyse significant differences in survival time between patients with prostatic malignancy and urinary bladder malignancy (Paper V).
PERCUTANEOUS NEPHROSTOMIES

RESULTS

Enhancement of planning for an optimal insertion of percutaneous nephrostomy prior to percutaneous nephrolithotripsy - Biomodelling

In Paper IV, biomodels of the pelvo-calyceal system were created. A problem occurred during the manufacturing process, in that the calculi and the contrast filled pelvo-calyceal system had overlapping attenuation values on the CT scans. In the first models, the aim was to perform only one CT series in the excretory phase, but it proved impossible to separate the calculi from the collecting system in the CAD model. Instead we had to perform two series, one in native phase and one in an excretory phase. The two phases had to be fused and matched to create the CAD model.

In order to visualise the kidney stones in the cavity, the biomodels of the collecting system had to be transparent. Initially, the borders of the pelvo-calyceal system and the calculi were created as separate parts which were assembled (Fig. 8). In order to get the correct anatomical view, the different parts had to be matched with the CT images. Later, the stones were created as preformatted empty spaces within the plastic model of the collecting system. The cavities were filled out with dyed liquid through drilling canals (Fig. 9). Later, the areas in the biomodels that contained stones were manufactured by means of

![Fig. 8.](image)
Early biomodel with the borders of the pelvo-calyceal system and the calculi performed as separate parts. (Colour print available in the supplement, page 39.)

![Fig. 9.](image)
Biomodel where the kidney stones were created as preformatted empty spaces within the biomodel. The cavities were filled out with liquid colour by drilling canals. (Colour print available in the supplement, page 39.)
Fig. 10.
Biomodel (oblique lateroanterior view) with a 40x25 mm staghorn calculus and two 8 respectively 9 mm calculi in the lower calyces extending to the renal ampulla. Puncture was performed to a lower dorsally directed stone containing calyx (arrow).
(Colour print available in the supplement, page 39.)
multiple laser scans, creating a darker area in the bio-
model, better illustrating the calculi (Fig. 10). Eight
cases with complex urinary calculi were summarised
demonstrating that the semitransparent model offers
visualisation of body cavities without the need for
mental reconstructions. The model both facilitates
preoperative planning and serves as a reference dur-
sing surgery.

**The incidence of complications related to indication, modality and puncture location**

In Paper I, the patients suffered from nephrolithiasis
and were referred for PCN insertion prior to treat-
ment with PCNL.

The complications occurred pre-, per- and postop-
erative. All the supracostal (n=17) and 81% (n= 51)
of the subcostal punctures were performed by expe-
rienced uroradiologists.

Preoperative complications were registered in 15
patients (17%). The main difference between the su-
pra- versus the subcostal group was the number of
patients who complained of respiratory correlated
pain. In the supracostal group there were 7 (32%)
and in the subcostal group 3 patients (5%). In the
supracostal group there were 2 (9%) pneumothora-
ces, both managed conservatively.

Peroperatively, there were 12 patients registered
with bleeding, 5 of which required blood transfu-
sions. No significant difference was observed regard-
ing peroperative complications in the two groups.

Postoperatively, there were two major bleeds, one
in each group. They were both treated with arterial
embolisation. Two hydrothoraces were identified in
the supracostal group.

In Paper II, there was an overall success rate of
98% when given two attempts to obtain access to
the renal pelvis. 593 (93%) of the procedures were
performed as an emergency treatment.

Complications when performing PCN were divid-
ed into major and minor complications.

Major complications included cardiac arrest,
bleeding requiring transfusion or embolisation, sep-
ticaemia, hydrothorax, pneumothorax or venous
thrombosis.

There were 22 (4%) major complications. There
were no deaths, but one patient had a cardiac arrest
within the first two days and was resuscitated. Three
patients had bleeds, one requiring embolisation and
two requiring blood transfusions. 15 of the proce-
dures (3%) were followed by sepsis; two within two
days, two between two days and two weeks and 10
after two weeks. In six of these cases, the catheter
was displaced (Table 1).

<table>
<thead>
<tr>
<th>Complications</th>
<th>&lt;2 days post PCN</th>
<th>2 days to 2 weeks post-PCN</th>
<th>&gt;2 weeks post-PCN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cardiac arrest</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bleeding requiring transfusion</td>
<td>1</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Bleeding requiring embolization</td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Hydrothorax</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abcess</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urosepsis</td>
<td>2</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>Deep venous thrombosis</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Major complications of PCN insertion and treatment.
Minor complications included urinary tract infection, catheter dislodgement, catheter obstruction by debris, urinary leakage and inflammation of the skin at the site of the PCN insertion. Minor complications occurred in 38% of the procedures. 77 (14%) of patients suffered from urinary tract infection at some time during the PCN treatment. In patients with long-term PCN treatment (at least one PCN change) 27% suffered from at least one urinary tract infection.

**Follow-up and outcome in percutaneous nephrostomy treated patients**

In Paper II, 95 (24%) of 401 patients required permanent PCN treatment and died with the catheter still in place. 79 (14%) of the catheters slipped out.

In Paper V, 84 (56%) of the patients with malignant disease died with the catheter. The clinical endpoints for the various types of malignancies are shown in Table 2. 11 (7%) of the catheters slipped out, and new catheters were not inserted owing to the poor status of the kidney or the patient. 16 patients were treated with alternative treatment including J-stents and thermoexpandable ureteric stents. Successful therapy, either medical or surgical, was obtained in 38 patients (25%). Median survival time of the patient was 255 days. The survival times for patients with different types of malignancy are presented in Fig. 11. The longest survival times were seen in the groups with urinary bladder malignancy (530 days) and gynaecological malignancy (938 days). The shortest median survival time was seen in the groups with colorectal malignancy (130 days) and prostatic malignancy (207 days). There was a significant difference in survival time between the group with urinary bladder malignancy and prostatic malignancy (p=0.00558). The median catheterisation time for all patients was 62 days. The catheterisation times for patients with different types of malignancy are presented in Fig. 12. The longest median catheterisation time was seen in the group with gynaecological malignancy (114 days) and prostatic malignancy (87 days), and the shortest in the group with urinary bladder malignancy (48 days), colorectal malignancy (51.5) days and other malignancies (60 days).

The highest number of deaths with a patent PCN were seen in the groups with colorectal malignancy (81%) and prostatic malignancy (69%). Successful therapy was most often obtained in the groups with urinary bladder malignancies (44%) and gynaecological malignancies (45%).

<table>
<thead>
<tr>
<th>End point</th>
<th>Prostatic malignancy (n = 55)</th>
<th>Urinary bladder malignancy (n = 43)</th>
<th>Gynaecological malignancy (n = 11)</th>
<th>Colorectal malignancy (n = 16)</th>
<th>Other malignancies (n = 26)</th>
<th>All malignancies (n = 151)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Death, functioning PCN</td>
<td>38 (69%)</td>
<td>16 (37%)</td>
<td>3 (27%)</td>
<td>13 (81%)</td>
<td>14 (54%)</td>
<td>84 (56%)</td>
</tr>
<tr>
<td>Converted to alternative treatment</td>
<td>7 (13%)</td>
<td>5 (12%)</td>
<td>1 (9%)</td>
<td>0</td>
<td>3 (12%)</td>
<td>16 (11%)</td>
</tr>
<tr>
<td>Successful therapy, PCN withdrawal</td>
<td>5 (9%)</td>
<td>19 (44%)</td>
<td>5 (45%)</td>
<td>2 (13%)</td>
<td>7 (27%)</td>
<td>38 (25%)</td>
</tr>
<tr>
<td>PCN withdrawal, endstage patient</td>
<td>4 (7%)</td>
<td>2 (5%)</td>
<td>2 (18%)</td>
<td>1 (6%)</td>
<td>2 (8%)</td>
<td>11 (7%)</td>
</tr>
<tr>
<td>Continued PCN treatment</td>
<td>1 (2%)</td>
<td>1 (2%)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2 (1%)</td>
</tr>
</tbody>
</table>

**Table 2.**
Endpoints, analysis by site of primary malignancy.
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Fig. 11.
Survival times for patients with different types of malignancies.

Fig. 12.
Catheterisation times for patients with different types of malignancies.
In Paper III, the puncture was successful on the first attempt in 13 out of 15 patients undergoing biopsies, and in both of two patients receiving drainage catheters. In the two patients where the needle did not hit the target, the tumours were small and the patients had problems repeating the same breathing position.

The mean difference between calculated and final needle angle was 2.4°±2.4° (0-8°) for Observer A and 2.2°±2.9° (0-9°) for Observer B. The mean difference between the angle of the streak artefact and the final needle angle was, for Observer A and B respectively, 1.1°±1.3° (0-4°) and 1.1°±0.9° (0-3°). The mean quality of the streak artefact was graded 2.6°±0.8 (1-3) by Observer A and 2.7°±0.6 (1-3) by Observer B. The difference between the two observers regarding the angle of the artefact was 0.8°±0.7 (0-2°).
GENERAL DISCUSSION

Biomodels have been found useful for preoperative planning in complex orthopaedic, craniofacial and neurosurgery (32, 33, 34). To our knowledge, the use of biomodelling in planning for endourological procedures has not previously been reported. In Paper IV, biomodels were created as an aid to obtaining optimal access to urinary calculi in PCNL treatment. The semitransparent biomodel offered the surgeon visualisation of body cavities and spatial information without the need for mental reconstructions of multiple organs. The possibility of facilitating preoperative planning and rehearsal probably contributes to reducing the operating time. Shortening surgery could, hypothetically, minimise additional surgical trauma, blood loss and postoperative complications.

In Paper II, 550 of 569 PCN procedures were successful at the first attempt; an additional eight of the cases obtained access to the pelvo-calyceal system at the second attempt. The incidence of placement success was 98%, which is comparable to other series (35). PCN procedures generally are safe. In our material we reported an incidence of major complications of 4% (Paper II).

To minimise the number of complications, certain precautions should be followed. A preprocedural evaluation of the patient should be performed. Marked coagulopathy or thrombocytopenia should be corrected. Antibiotics should be administered routinely preoperatively. The incidence of septicaemia in Paper II was 3%, which is similar to previous studies (35, 36). Cochran et al. reported that, in their high-risk group, 50% developed evidence of sepsis without antibiotics and only 9% with antibiotic cover (19).

To minimise the risk of renal vascular damage when performing PCNL, it is important for the radiologists to obtain adequate visualisation of the calyces. In Paper I there were 12 patients (14%) with preoperative bleeding, five (6%) of these requiring transfusion of at least one unit of blood. These numbers are comparable with other reports (18, 35, 37). However, no significant difference regarding preoperative complications were found between the supracostal versus the subcostal group.

Puncture should be performed subcostally if possible. However, a supracostal approach is sometimes preferable when performing PCN as a prelude to further interventions, such as PCNL (38, 39, 40). Puncturing the upper calyx is more direct to the long axis of the kidney, giving a smoother passage of the rigid instruments toward the lower pole. The posterior part of the diaphragm arises from the tip of the 10th to the 12th rib posteriorly (7). The caudal border of the lung normally lies at the level of the 10th thoracic vertebrae posteriorly, but may vary with the patients’ age, constitution and posture, inspiration and lung disease. Owing to these anatomic relations, a supracostal puncture above the 12th rib will always traverse the diaphragm. The possibility of injuring the lower lobe of the lung or the pleura should also be considered. According to Hopper et al. (28), when patients are in prone position and in full expiration, needles inserted via an intercostal approach between the 11th and 12th ribs would be expected to puncture the left lung in 14% and the right lung in 29% of cases. In the same series of patients, puncture of the lung would occur in 86% to 93% of patients with an intercostal approach between the 10th and 11th rib, right and left side respectively. This reinforces the importance of differentiating between supracostal (above the 12th rib) and subcostal puncture, and between a supracostal approach between the 11th and 12th rib and the 10th and 11th rib. In Paper I, 26% of the procedures were performed through a supracostal approach. In the study group there were two patients suffering from pneumothorax in the supracostal group. A CT-guided puncture would provide better anatomical mapping (42), avoiding a laceration of the lung or air entering the
pleural space via the nephrostomy. However, one of the patients with pneumothorax underwent a CT-guided puncture and this reflects difficulties in identifying the “pleural line”. The higher incidence of respiratory correlated pain in the supracostal group is probably also a reflection of the difficulties in visualising the “pleural line” in CT as well as fluoroscopic techniques. To reduce inconvenience for the patient, our aim is to perform the puncture in as short a time as possible preoperatively. Postoperatively, the catheter should be removed as soon as possible. If the patient still needs a urinary diversion, a new subcostal catheter should be inserted.

Our overall complication rate related to the supracostal approach (pneumo-hydrothorax) was 18%, which is slightly higher than reported by others: 8.7% (41), 12% (35) and 12.5% (18). However, an increased number of minor complications might be accepted in cases that would benefit from supracostal punctures to achieve a more direct and optimal access to complex calculi or for further interventions.

In our study (Paper II), a large group of PCN complications were associated with the catheter rather than procedure related. In 2% of patients, there was catheter displacement, which required fluoroscopic repositioning. Catheter occlusion was seen in 4%, requiring exchange of the catheter or flushing. The figure for catheters that slipped out (14%) is similar to other studies (17, 43). 14% of the procedures were followed by urinary tract infection at some time during PCN treatment; in patients with long-term PCN treatment (at least one PCN change) this number rose to 27%. The high rate of urinary tract infections in patients with prolonged PCN treatment suggests the use of long-term antibiotic prophylactics in patients with underlying valvular heart disease and patients at risk of bacteremia.

Many of the patients with long-term PCN treatment suffer from malignancy, and the nephrostomies are often intended to be used as a temporary measure before receiving beneficial anti-cancer therapy. In our study of patients with malignancies, Paper V, the PCN was removed in 38 of 151 patients (25%) due to successful therapy. Additional alternative methods to divert urine from the collecting system include double J-stents inserted by antegrade or retrograde route and thermoexpandable ureteric stents (Memokath, Engineers & Doctors A/S, Kvistgaard, Denmark). These procedures were undertaken in 16 of the 151 patients in our study. The advantages of stent treatment are that there is no requirement for external drainage with a consequent improvement in quality of life (44). Double J-stents inserted by the antegrade route are usually easy to insert and this procedure may be performed under local anaesthesia. Double J-stents inserted either by retrograde or antegrade route may irritate the bladder, causing symptoms such as frequency, dysuria and flank discomfort. Moreover, if the stent is blocked by detritus, this is not noticed until the patient gets symptoms such as flank pain, infection or uremia. Therefore there is no control of the drainage. Other drawbacks are the formation of encrustation, stent migration and higher costs than PCN insertion costs. To prevent the formation of encrustation, double J-stents have to be exchanged regularly (in our hospital every 12 weeks). Double J-stents inserted by antegrade route as a two-stage approach cause few complications and may be performed in a semi-elective fashion (45). However, success rates with antegrade stenting in patients with malignancies causing obstruction in the lower ureter have been reported to be low (45, 46). In our study of patients with malignancies, those with urinary bladder tumours made up the second largest group. In this group, obstruction of the lower ureters may be caused both extrinsically by pressure on the ureters and by invading the ureteral orifices, making stent placement difficult. Extrinsic pressure may also obliterate the stent, resulting in insufficient drainage. In urinary blad-
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der malignancies, PCN treatment has been shown to be the most appropriate and safe diversion technique (47).

The thermoexpandable ureteric stent has been designed to relieve ureteral obstruction and, since it only occupies the obstructed ureteral segment, it does not cause the unwanted irritative symptoms of double J-stents. A further benefit of the thermoexpandable ureteric stent is prolonged patency, although tumour ingrowth and endothelial hyperplasia often lead to recurrent obstruction (48). An additional advantage is that no stent changes are required with the thermoexpandable ureteric stent and there is therefore no need for frequent hospitalisation.

Shorter insertion times and fewer analgesics have been reported with nephrostomies than with stent diversion (49). The PCN requires an external drainage, which impairs the quality of life. Other drawbacks are the need to manage the PCN regularly and that, to avoid blockage of the PCN, the catheters have to be exchanged regularly (in our institution, every 12 weeks).

Even if PCN treatment is intended as a temporary measure, many of the patients die with their PCN (84 patients in our study). The selection of patients to be treated with PCN in the group of patients with malignancies is important. In some cases, where there is no expectation of a return to a satisfactory life, and when survival-time is expected to be short, patients may be allowed to progress to relatively painless uraemia.

In order to increase accuracy when performing CT-guided punctures, a new puncture guidance device may be used. A first clinical study of the new device is described in Paper III. In 15 out of 17 punctures, the target was hit on the first needle pass. The mean difference between calculated and final needle angle between the two observers was respectively $2.4^\circ$ and $2.2^\circ$, indicating that the needle guide promoted an accurate needle pass. The benefit of the needle guide is the support it provides, which enhances a faster and more accurate puncture. There is no need to support tissue in the body because of the needle support provided by the needle guide. The artefact pointing at the goal serves as a good indicator of the needle path and as verification that no vital structures pass the planned path.

The drawback with the needle guide is that the present needle guide only can be angled $\pm 30^\circ$. However, further developments are in progress in order to increase the angulation to $\pm 60^\circ$. 
CONCLUSIONS

- The use of biomodels of the kidney and kidney stones enhances preoperative planning so as to increase the certainty in PCN of reaching the specific target in the kidney prior to PCNL. The biomodels allow imaging data to be displayed in a physical form, which may improve the treatment as well as communication between colleagues and patients.

- PCN is a safe procedure associated with a high success rate and few major complications.

- The complication rate is slightly higher after supracostal puncture as compared to the subcostal approach.

- The majority of patients with malignancies treated with PCN have advanced disease and a relatively short survival time.

- A urinary diversion treatment that does not impair quality of life and is combined with low costs is optimal in patients with malignancies who have a short median survival time and short median catheterisation time. Therefore, PCN should be considered as a treatment option in these patients.

- The new CT guidance device promotes an accurate needle pass because of its needle support and the artefact pointing at the target.
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ACKNOWLEDGEMENTS

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SUMMARY IN SWEDISH

Perkutana nefrostomier- planering för att erhålla optimal access, komplikationer, uppföljning och utgång.

Perkutan nefrostomi är en väl etablerad metod, som vid avflödeshinder utförs för att avleda urin från njurens samlingsystem eller inför planerad interventionell åtgärd såsom inläggning av stent, endoskopi och perkutan stenkirurgi. Syftet med denna avhandlingen var att utveckla en teknik för att optimera och underlätta den preoperativa planeringen inför inläggandet av perkutan nefrostomi. Att öka precisionen vid insättandet av perkutan nefrostomi, för att på så sätt även kunna reducera antalet komplikationer.

De specifika målen med studien var:

• att underlätta planeringen för att erhålla optimal väg till njuren vid perkutan stenextraktion.
• att undersöka incidensen av komplikationer till perkutan nefrostomibehandling i relation till indikation, modalitet och punktionens lokalisation.
• att studera långtidsuppföljning och utgång vid nefrostomibehandling.
• att öka precisionen vid datortomografiskt vägledda punktioner.


För att utvärdera komplikationer i samband med nefrostomierbehandling utfördes en studie på 85 patienter vilka remitterats för nefrostomi inför perkutan stenkirurgi. En subcostal punktion, under 12:e revbenet, genomfördes i 63 av fallen, och i de resterande fallen utfördes en supracostal punktion. Den största skillnaden mellan de två grupperna var antalet patienter vilka klagade på andningskorrelaterade smärtor. I den supracostala gruppen var dessa 7 (32%) och i den subcostala gruppen 2(9%). Två fall av pneumothorax noterades i den supracostala gruppen. För att undersöka komplikationer i samband med perkutan stenkirurgi utfördes en studie på 401 patienter, där varav 85 patienter kom att behöva perkutan nefrostomibehandling. Allvarliga komplikationer inkluderande hjärtstillestånd, blödning vilken krävde blodtransfusion eller embolisering, sepsis, hydrothorax, pneumothorax inträffade i 4% av fallen. Mindre komplikationer
omfattande urinvägsinfektion, kateterdislokation, kateterocklusion, urinläckage och hudinflammation vid instickstället noterades i 38% av fallen.

151 av patienterna utgjordes av patienter vilka led av malignitet. Majoriteten av dessa patienter (56%) dog med kateter. Medianöverlevnaden var 255 dagar, och mediankatetrisingstiden var 62 dagar.

För att öka precisionen vid CT ledda punktioner utvecklades ett nytt punktionshjälpmedel. Sjutton patienter remitterade för CT ledda punktion inkluderades i studien. Femton av de sjutton punktionerna lyckades vid första försöket. I de två fall där punktionens målet inte nådde fick tumörerna små och patienterna hade svårighet att hålla andan i samma position. Fördelarna med punktionshjälpmedlet var att det bildades en artefakt från nålguiden som pekade mot det givna målet, nålen stabiliserades och hjälpmedlet bidrog till en ökad precision vid CT ledda punktioner.
PERCUTANEOUS NEPHROSTOMIES

REFERENCES


COLOUR SUPPLEMENT

Colour figures from thesis and from papers originally in colour.

Thesis - Fig. 8.

Thesis - Fig. 9.

Thesis - Fig. 10.
Thesis - Fig. 2, Paper I - Fig. 1b.

Thesis - Fig. 6, Paper III - Fig. 3.
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Paper IV - Fig. 1c.

Paper IV - Fig. 1d.

Thesis - Fig. 3, Paper IV - Fig. 1e.

Thesis - Fig. 4, Paper IV - Fig. 1f.