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Hardness and Morphological Characteristics of Renal, Gallbladder, and Salivary Gland Stones and Their Clinical Intervention Strategies

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Abstract Objective: To explore the hardness and morphological characteristics of kidney, gallbladder and salivary gland stones and clinical intervention strategies. **Methods:** 97 patients with kidney, gallbladder and salivary gland stones from January 2024 to May 2025 were selected as subjects and divided into kidney stone group (n=44 cases), gallstone group (n=39 cases) and salivary gland stone group (n=14 cases) according to the type of stones. All three groups completed CT examinations after admission to evaluate the hardness of different types of stones. All patients completed ultrasound examinations to evaluate the morphological characteristics of different types of stones. Corresponding clinical intervention strategies are proposed for different types of stones. **Results:** The CT value of the kidney stone group was higher than that of the gallstone group and salivary gland stone group (P<0.05). The CT value of the salivary gland stone group was higher than that of the gallstone group (P<0.05). Different stones exhibit varying physical and chemical properties, but some overlap, including primary composition, hardness, color, and shape, increasing the difficulty of clinical differentiation. Kidney stones present as hyperechoic masses on ultrasound. Gallstones present as stable hyperechoic masses within the gallbladder cavity on ultrasound. Salivary gland stones present as stable hyperechoic masses within the duct. Submandibular gland stones are often fusiform or oval with a smooth surface. Parotid gland stones are often irregular in shape with a rough surface. **Conclusion:** The

hardness and morphological characteristics of different stone types directly influence the choice of intervention strategy. Kidney stones, due to their high hardness and irregular shape, require minimally invasive surgical intervention. Gallstones, due to their complex composition, require a differentiated approach between cholesterol and pigment stones. Salivary gland stones, due to their unique anatomical location, are often treated with endoscopic surgery.
Keywords: Kidney Stones, Gallstones, Salivary Gland Stones, CT Scan, Ultrasound, Morphological Characteristics, Intervention Strategy

The global incidence of kidney stones continues to rise, with the annual incidence in industrialized countries reaching 1.0%-2.0%. However, the incidence in southern my country is slightly higher than in the north due to the hot and humid climate. It can cause renal colic and hematuria, and in severe cases, hydronephrosis and renal failure [1]. Gallstones account for more than 90.0% of gallbladder diseases, and the incidence in women is slightly higher than that in men. The risk increases with age, and it can cause biliary colic and jaundice, and even induce acute pancreatitis and gallbladder cancer. Although salivary gland stones are relatively rare, submandibular gland stones account for more than 80.0% of salivary gland stones, which can easily cause recurrent infections and affect the quality of life of patients [2]. The composition of kidney, gallbladder, and salivary gland stones is diverse, and their morphology is affected by the composition and formation environment. The difference in stone hardness directly affects the choice of treatment method. For example, hard stones require high-energy lithotripsy, while soft stones can be treated with drug dissolution [3]. Bind RH et al. [4] showed that stone hardness and morphology are closely related to the patient's age, gender, and metabolic status. For young female patients with uric acid stones, non-invasive stone dissolution can be achieved by alkalinizing the urine, while elderly male patients with calcium oxalate stones require surgical intervention. Existing guidelines are mostly based on stone size and location, and insufficient consideration is given to hardness and morphology, leading to over- or under-treatment [5]. This study aims to explore the hardness and morphological characteristics of kidney, gallbladder, and salivary gland stones and clinical intervention strategies, as reported below.

1 Subjects and Methods

1.1 General Data

A total of 97 patients with renal, biliary, and salivary gland stones were enrolled between January 2024 and May 2025. According to stone type, they were divided into a renal stone group (n = 44), a gallstone group (n = 39), and a salivary gland stone group (n = 14). No statistically significant differences in general information were found among the three groups (*P*>0.05). (See Table 1.)

Table 1 Comparison of general information among the three groups

Group	Number of cases	Gender (male/female)	Body mass index (kg/m ^{2})	Age (years)	Comorbidities (yes/no)	History of smoking and drinking (yes/no)	Disease duration (d)
Kidney stone group	44	27/17	22.31±2.42	59.39±4.51	13/31	17/27	7.39±1.23
Gallstone group	39	16/23	22.35±2.45	57.11±4.58	10/29	12/27	7.32±1.18
Salivary gland stones group	14	8/6	22.28±2.38	57.86±4.53	5/9	3/11	7.34±1.20
χ^2/F	/	3.567	0.005	2.667	0.527	1.568	0.036
P	/	0.168	0.995	0.075	0.768	0.457	0.965

1.2 Inclusion and Exclusion Criteria

Inclusion criteria: (1) Patients who meet the diagnostic criteria for renal, gallbladder, and salivary gland stones in the "Guidelines for the Application of Biliary Endoscopic Treatment of Hepatobiliary Stones (2024 Edition)" [6]. (2) All patients were diagnosed by imaging examinations and biochemical index examinations. (3) All patients had no contraindications to CT and ultrasound examinations, were conscious, and able to communicate. Exclusion criteria: (1) Patients with mental disorders, coagulation disorders, or confirmed malignant tumors. (2) Patients with severe liver and kidney dysfunction, blood system diseases, or cognitive impairment. (3) Patients with autoimmune system diseases and systemic infectious diseases.

1.3 Methods

1.3.1 Stone Hardness Test

① Kidney Stone Examination. 1. Preparation Before the Examination. Patients start eating the day before the examination to avoid interference from foods high in calcium, protein, and purine. Patients should drink plenty of water before the examination to fill the kidneys and facilitate detection of small stones. Wear loose clothing and remove any metal objects. 2. Examination Procedure. Lie supine with hands on the head, keeping body midline aligned with the midline of the examination bed. Scan layer by layer from the upper to lower pole of the kidney, covering the entire kidney and the beginning of the ureter. During the examination, follow the machine's commands to breathe calmly or hold patients breath to avoid motion artifacts. CT scans are used to determine stone density, and stone shape, location, and the presence of hydronephrosis are observed. ② Gallstone Examination. 1. Preparation Before the Examination. Fast for at least 8 hours before the examination to fully dilate the gallbladder. Patients suspected of having common bile duct stones may drink 800-1000 mL of water. 2. Examination Procedure. Lie supine, covering the entire gallbladder and biliary system, with a focus on the cystic duct and the lower common bile duct. During the scan, Patients need to hold their breath to avoid missing small lesions due to layer jumps. The density of the stones is judged by the CT value, which indirectly reflects the hardness of the stones. High-density stones have a CT value >25HU and are easy to display. Low-density stones have a slightly lower CT value and appear as translucent shadows. Annular stones show high density at the edge and low density in the center.

③ Salivary gland stone examination. 1. Preparation before the examination. No special fasting is required, and metal objects should be removed. 2. Examination process. Choose a suitable body position according to the location of the stone. For the anterior part of the submandibular duct stone, choose the mandibular transverse film position. The alternative is to choose the submandibular gland positioning film position. For parotid stones, choose the parotid lateral film position. The scanning range covers the entire salivary gland and duct system, focusing on the location of the stone.

1.3.2 Morphological feature examination

(1) Kidney stone examination. ① Lateral or prone position. Scan the ureteral long axis coronally, using the kidneys or renal pelvis as a landmark to show the ureteropelvic junction, and then trace the scan downward to the first ureteral stricture. ② Supine position. Scan the inferior vena cava or abdominal aorta 1-2 cm lateral to the longitudinal direction. Look for the dilated abdominal ureter and trace the scan downward to the pelvic ureter. Use the end of the common iliac artery or the external iliac artery as a landmark to look for the dilated ureter in front of it, and adjust the probe direction to show the second stricture. ③ The bladder is an acoustic window. Use the ureteral opening as a landmark to adjust the probe direction upward to retrogradely scan the bladder wall and pelvic ureter. ④ Dynamic observation. Use color Doppler blood flow imaging to observe the urine spraying from both ureters and complete the morphological feature analysis. (2) Gallstone examination. ① Preparation before examination. Fast for more than 8 hours and fully expand the gallbladder to facilitate observation of the gallbladder wall and stones. Oral positive contrast agent is administered to fill the intestine to avoid gas interference. ② Body position. Routinely scan the long axis section of the gallbladder in the supine position to observe the size, shape, and internal echo of the gallbladder. The gallbladder bottom is close to the abdominal wall in the right lateral position. ③ Dynamic observation. Change the body position, instruct the patient to take a deep breath or turn over, observe the movement of the stone, observe the blood flow signal of the gallbladder wall with color Doppler blood flow imaging, and complete morphological observation. (3) Examination of

salivary gland stones. ① Preparation before examination. No special fasting is required, and metal objects should be removed. ② Examination process. Routinely scan the parotid, submandibular, and sublingual glands in the supine position to observe the size, shape, and internal echo of the glands. The supine position allows the glands to be close to the abdominal wall. ③ Dynamic observation. Press the glands to observe the dilation of the duct and the movement of the stones, observe the gland blood flow signal, and propose corresponding clinical intervention strategies for different types of stones.

1.4 Observation Indicators

(1) Stone hardness. Statistically calculate the CT values of the three groups to indirectly reflect the hardness of the stones. (2) Stone morphological characteristics. Compare the main components, hardness, color, and shape of different types of stones, and further compare the morphological characteristics of different stones under ultrasound.

1.5 Statistic Analysis

SPSS 28.0 software was used for data analysis. Count data such as gender, comorbidities, and smoking and drinking history were analyzed using the χ^2 test and expressed as n (%). Quantitative data such as age, body mass index, course of disease, and stone hardness were all normally distributed. F-tests were used for comparison of multiple groups of data, and independent t-tests were performed between groups, expressed as ($\bar{x} \pm s$). P<0.05 indicated statistical significance.

2 Result

2.1 Comparison of stone hardness among the three groups

The CT value in the kidney stone group was higher than that in the gallstone and salivary gland stone groups (P<0.05). The CT value in the salivary gland stone group was higher than that in the gallstone group (P<0.05). See Table 2.

Table 2 Comparison of stone hardness among three groups ($\bar{x} \pm s$)

Group	Number of cases	CT value
Kidney stone group	44	896.87±85.38 #*

Gallstone group	39	95.59±10.27 #
Salivary gland stones group	14	874.79±67.81
F	/	1841.285
P	/	0.000

Note: Compared with the salivary gland stones group, # $P < 0.05$. Compared with the gallstones group, * $P < 0.05$.

2.2 Comparison of the three groups' physical and chemical properties

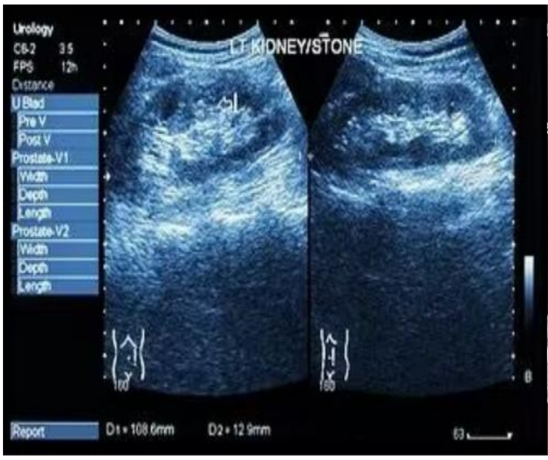
Different stones have different physical and chemical properties, but there are also overlaps, including: main components, hardness, color and shape, which increases the difficulty of clinical identification (see Table 3).

Table 3 Comparison of physical and chemical properties of three groups

Physical and chemical properties	Kidney stone group	Gallstone group	Salivary gland stones group
Main ingredients	Calcium oxalate, calcium phosphate, uric acid	Cholesterol, bile pigments, calcium salts	Calcium phosphate, mucopolysaccharides and glycoproteins
Hardness (Mohs)	Levels 1-4	Levels 1-3	Levels 2-4
color	Yellow, brown and black	White, yellow, black	Yellow, light yellow and brown
shape	Irregular granular, mulberry-shaped	Round, oval and branch-shaped	Spindle, round and cylindrical

2.3 Comparison of morphological characteristics among the three groups

Ultrasound examination of kidney stones reveals a hyperechoic mass with a posterior acoustic shadow. Stone morphology varies between calcium oxalate stones (star-shaped, mulberry-shaped, with a rough surface), uric acid stones (antler-shaped, smooth, with a faint acoustic shadow), and smaller stones (punctate, hyperechoic, without an acoustic shadow) . Gallstones present with a stable, hyperechoic mass within the gallbladder cavity under ultrasound, with a posterior acoustic shadow. Cholesterol stones are often round or oval, solitary or multiple, and large in size. Pigment stones are silt- or gravel-like, accumulating on the posterior gallbladder wall. Mixed stones are irregular in shape with a rough surface. Stable, hyperechoic masses are present within the salivary gland duct. Submandibular gland stones are often fusiform or oval, with a smooth surface. Parotid gland stones are often irregular in shape with a rough surface (see Figure 1).



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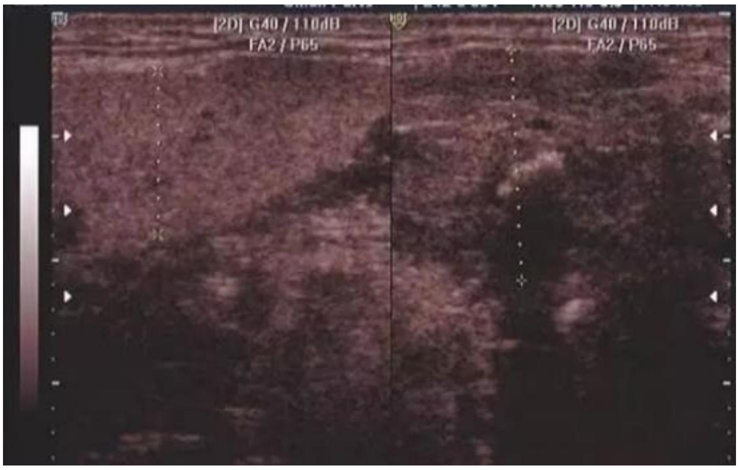

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Figure 1 Ultrasound images of typical cases

Note: Figure A is an ultrasound image of kidney stones. Figure B is an ultrasound image of gallstones. Figure C is an ultrasound image of salivary gland stones.

3 Discussion

There are many types of kidney stones, including calcium oxalate stones, calcium phosphate stones, uric acid stones, magnesium ammonium phosphate stones, and cystine stones.[7] Among them, calcium oxalate stones account for a relatively high proportion. They are as hard as stone and have a rough surface, which can easily scratch the ureter and cause bleeding. Calcium phosphate stones are harder but more fragile than calcium oxalate stones. They have a grayish-white or antler-shaped surface and are associated with metabolic abnormalities. Kidney stones are mainly round, oval, irregular, or mulberry-shaped, and range in size from sand-like to several centimeters.[8] Gallstones include cholesterol, bile pigment, mixed, and mud-like stones. Among them, cholesterol stones account for a relatively high proportion. They are hard, have a smooth surface, and are mostly light yellow or yellow-white in color. They are associated with cholesterol oversaturation in bile.[9] Gallstones are mainly round, oval, or irregular in shape, and range in size from sand-like to walnut-shaped (cholesterol stones are larger in size).[10] Salivary gland stones are usually hard, yellow or yellowish brown, slightly jagged, and about the size of a pea [11]. In this study, the CT value of the kidney stone group was higher than that of the gallstone group and the salivary gland stone group ($P < 0.05$). The CT value of the salivary gland stone group was higher than that of the gallstone group ($P < 0.05$). Different stones have different physical and chemical properties, and there are also overlapping parts, including: main components, hardness, color and shape, which increases the difficulty of clinical identification and affects the choice of treatment for patients.

In this study, patients with kidney stones showed strong echo masses under ultrasound. Gallstones showed stable strong echoes in the gallbladder cavity under ultrasound. Salivary gland stones showed stable strong echoes in the duct. Submandibular gland stones were mostly spindle-shaped or oval with smooth surfaces. Parotid gland stones were mostly irregular in shape with rough surfaces. From this result, it can be seen that the hardness and morphological characteristics of kidney, gallbladder and salivary gland stones are different. Clinical intervention should be taken according to different types of stones to promote stone excretion. (1) Kidney stones. For patients with stone diameter <0.6cm, smooth surface and no urinary tract obstruction, conservative treatment can be selected. Patients should be advised to drink more water, take oral stone-expelling drugs and exercise to promote stone excretion. For patients with stone diameter of 0.6-2.0cm and located in the renal pelvis or upper ureter, extracorporeal shock wave lithotripsy can be performed. For patients with diameter >2.0cm or failure of extracorporeal shock wave lithotripsy, percutaneous nephrolithotomy can be performed. For patients with lower calyx stones or obesity, ureteroscopic lithotripsy can be an option [12]. (2) Gallstones. Asymptomatic gallstones and cholesterol stones with a diameter of less than 1.0 cm can be treated conservatively [13]. For common bile duct stones, endoscopic retrograde cholangiopancreatography can be an option. For patients with symptomatic gallstones or complications, laparoscopic cholecystectomy can be performed [14]. (3) Salivary gland stones. For stones with a diameter of less than 0.3 cm and located in the anterior part of the duct, conservative treatment is performed. For intraductal stones, endoscopic salivary gland lithotomy can be selected. For palpable anterior ductal stones, intraoral ductotomy can be performed. For patients with recurrent glandular infection, loss of function, or inability to remove stones, gland resection is performed [15]. In summary, the hardness and morphological characteristics of different types of stones directly affect the choice of intervention strategy. Among them, kidney stones require minimally invasive surgical intervention due to their high hardness and irregular shape. Gallstones require a plan to distinguish between cholesterol and bile pigment stones due to their complex composition. Salivary gland stones are often treated with endoscopic surgery due to their special anatomical location.

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