Pancreatic ultrasound: An update of measurements, reference values, and variations of the pancreas

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ABSTRACT

Reliable and reproducible measurement methods have been established, and reference values are used in almost all scientific disciplines. Knowledge of reference values is crucial to distinguish physiological from pathological processes and, therefore, subsequently, for the clinical management of patients. Image storage and documentation of measurements and normal findings should be part of quality assurance in imaging. This paper aims to review the published literature and provide current knowledge of sonographic measurements and reference values of the pancreas. Moreover, the role of clinical influencing factors such as age, gender, constitution, and ethnicity is also analyzed.

Introduction

Why and when should pancreatic measurements be carried out? Normal values are used to detect deviations. Subjective impressions can be viewed objectively. Common indications for ultrasound of the pancreas are upper abdominal complaints, lipasemia, initial diagnosis, worsening of diabetes mellitus, acute and chronic pancreatitis, exocrine pancreatic insufficiency, obstructive jaundice, and other reasons for suspecting tumors. The measurements detect focal or generalized organ enlargement and can be used as baseline measurements for subsequent scans. Different examiners can also carry these out at various times. For example, the measurements are part of the follow-up checks and treatment decisions for autoimmune pancreatitis under cortisone therapy. In routine clinical practice, exocrine pancreatic insufficiency is a common laboratory finding that has to be matched with imaging to make treatment decisions. It is not only pancreatic diseases such as chronic pancreatitis, autoimmune pancreatitis, or cystic fibrosis that lead to exocrine pancreatic insufficiency. The natural pancreatic aging process is characterized by lipomatosis and fibrosis and may result in parenchymal atrophy and exocrine insufficiency [1, 2].

Main pancreatic duct (MPD) dilatation is associated with different pathologies that need to be assessed in conjunction with the patient's history, examination, and other findings such as pancreatic duct stones or calcification. It is one of the criteria for the diagnosis of chronic pancreatitis. It is rarely associated with intraductal papillary mucinous neoplasia of the main duct type, while MPD dilatation with downstream ductal stricture may indicate a malignant tumor. Minor dilatation of the MPD also occurs in older people in the context of parenchymal atrophy, MPD requires diagnostic clarification to detect a malignant tumor at an early stage [3].

It is not necessary to measure the pancreas in every patient. However, one should know the normal values to diagnose pathological deviations and disease criteria. It is vital to measure correctly, and this requires correct sonographic imaging of the pancreas.

In general, measurements allow the comparison of unknown quantities, e. g., an organ's length, width, thickness, and volume, with normal values or, in other words, known quantities [4]. These results allow quantitative statements on the diameters of an organ, duct, vessel, or any anatomic structure [5–7]. However, the measured values should not be seen in isolation but in the overall context of the clinical question, the patient's history, laboratory values, and findings in the other organ systems.

Image storage and documentation of measurements and normal findings should be part of quality assurance in imaging.

Aim

This paper aims to review the published literature and provide current knowledge of sonographic measurements and reference values of the pancreas, including limitations and pitfalls. In addition, the connection between ultrasound examination technique and reliable measurements, the influence of age, gender, constitution, ethnicity and other variables, the comparison of ultrasound measurements to measurements using other imaging techniques, and the clinical relevance of measurements are analyzed and illustrated. A comprehensive clinical evaluation should describe the pancreatic size and volume, pancreatic duct diameter, echogenicity, and elastographic properties. A selection of ultrasound measurements for the daily routine is given, together with practical advice on how to use them. In addition, anatomical and congenital variations and their possible clinical implications are summarized.

Material and Literature Review Methods

Three papers published in German journals between 2010 and 2012 reported the normal sonographic values for abdominal sonography [5–7]. An analysis of scientific literature published from 2011 to 2023 on reference values in pancreatic ultrasound was conducted for the current narrative review.

Search strategy

PubMed was searched for entries from 01/01/2011 to 17/02/2024 using the following keywords and binary operators: Pancreas AND (ultrasound OR ultrasonography OR sonography) AND (measurement OR sizing OR diameter OR width OR height OR length OR "reference value" OR "normative value" OR "cut-off value"). 2311 entries were identified in PubMed (final search date: 17.2.2024).

Study selection

Two of the authors independently reviewed titles and abstracts for eligibility. Animal studies, studies related only to pediatric cohorts (0–14 years), case studies (< 10 cases), editorials, letters to the editors, articles without English, German, French, or Spanish text, duplicates and articles referring not to the pancreas, articles including only measurements of pathologic conditions of the pancreas and articles only including non-ultrasound imaging modalities were excluded. Articles already included in the reference list of the review on reference values in biliopancreatic ultrasound published in 2011 [6, 8–32] were separately evaluated and partly included as the review was initially published in German only. Extensive cross-checking of the reference list of the retrieved articles was also performed. Disagreements regarding eligibility were resolved by discussion and consensus among all authors.

Data extraction

Data were extracted for the year of publication and imaging method used for pancreatic assessment (e. g., transabdominal ultrasound, endoscopic ultrasound, CT, MRI, shear wave elastography). Furthermore, data were sorted by selected pancreatic parameters (e. g., size, volume, pancreatic duct, fat content). For search results, see the flowchart ▶ **Fig. 1**.

Examination technique

Prerequisites for measurement (e. g., transducer type and frequency, position of the patient)

Patient preparation

- The planned examination should preferably be performed under fasting conditions, as food residues in the stomach may lead to artifacts limiting the sonographic assessment of the pancreas. Regardless, the advantage of an ultrasound examination is that it can be carried out at any time, especially in acute situations. However, better results are achieved

under fasting conditions (usually 4 to 6 hours, under study conditions often up to 8 hours).
- Drinking 500–700 ml of water 10–15 min. before examination can be considered.

Patient positions

- Standard position for measurements: supine position.
- Changing patient position is essential for optimal visualization of the pancreas:
  - 15–30 ° left (pancreatic head) or right (pancreatic tail) lateral oblique position.
  - Right or left decubitus position.
  - Seated or standing position.

Transducer type and initial transducer position

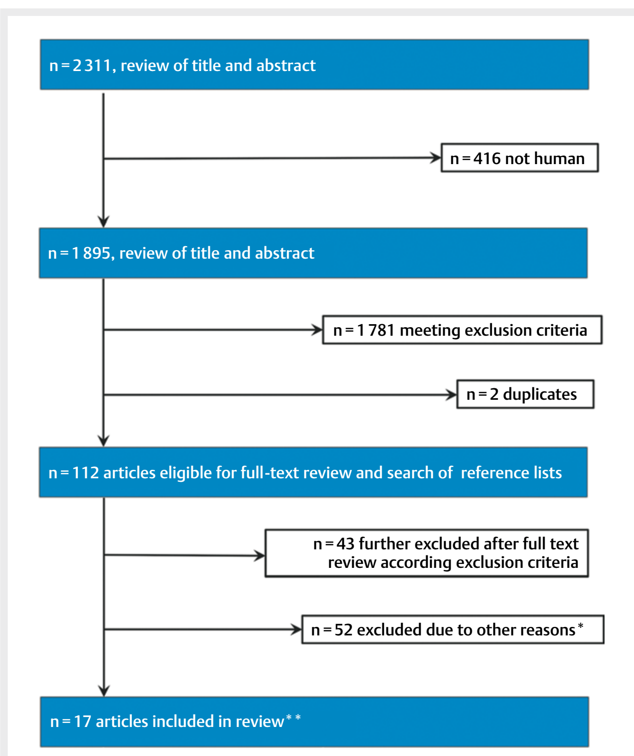
- Standard abdomen 2–7 MHz multifrequency curvilinear probe, positioned in the epigastric triangle directly below the sternum (subcostally and subxiphoidally) for the pancreatic head, body, and parts of the tail ▶ **Fig. 2–4** and an intercostal probe position in the 10th to 11th intercostal space for the left lateral parts of the pancreatic tail ▶ **Fig. 5**.

Ultrasound examination workflow and criteria

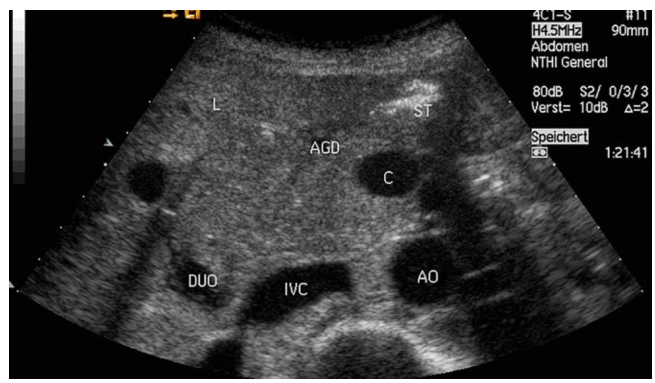
As a rule, the body of the pancreas is first shown in a cross-section over the splenic vein and superior mesenteric artery. To assess the head of the pancreas, the transducer is moved slightly clockwise to the patient's right and tilted caudally.

Visibility of the pancreas may be improved by repeat dosed compression with the US probe while the patient is breathing in and out and/or when the patient bulges out their abdomen. For mobile patients, better visualization can be attempted while standing ▶ **Fig. 2–5** ▶ **Table 1**.

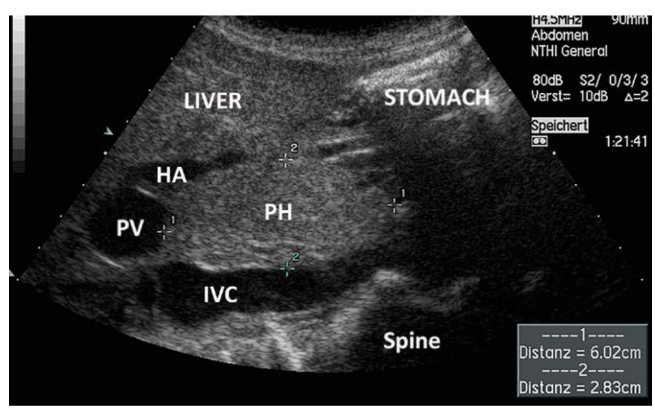
Due to the retroperitoneal location and proximity to ultrasound-reflecting structures (e. g., gas in the digestive tract), complete sonographic examination is often challenging. This is particularly true for the pancreatic tail. A previous Japanese study tried to quantify the possible "blind area" in ultrasound visualization of the pancreatic tail [33]. They investigated 39 patients using ultrasound with GPS-like technology and fusion imaging with CT. The real unobservable length of the pancreatic tail was estimated to be approximately 4 cm, accounting for approximately 25 % of the real



▶ **Fig. 1** Flowchart describing search strategy and selection of studies included in this review. *other reasons, e.g. same study population with follow-up, selection of most recent study version of same clinical question, same review topic. **further important references were included from 2010 and earlier according to the review by Sienz et al. and if very recently published during the last weeks and with important content.

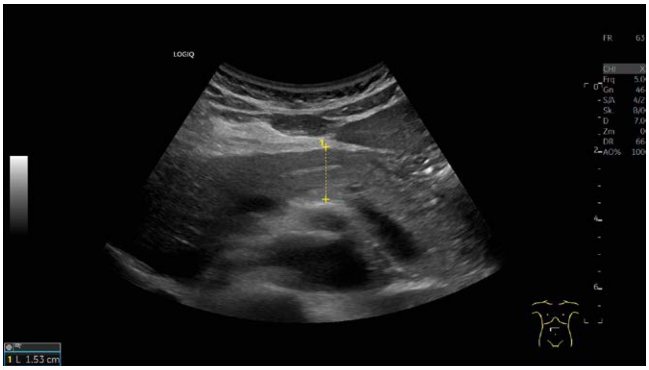


▶ **Fig. 2** The pancreas head is imaged in the transverse section and appears uniformly normal in size. L: Liver. ST: Stomach. AGD: Superior gastroduodenal artery. DUO: Duodenum. IVC: Inferior vena cava. AO: Aorta. C: Confluens (portal vein).



▶ **Fig. 3** In the right upper abdomen, with a transducer position slightly more caudal than for the pancreatic corpus, the normal pancreatic head is imaged. Longitudinal section with craniocaudal (60 mm) and anteroposterior measurements (28 mm). The liver, stomach, and spine are indicated. PH: Pancreatic head. IVC: Inferior vena cava. PV: portal vein. HA: Hepatic artery.

pancreatic length (mean 16 cm in this study). Using the intercostal approach, complete visualization of the pancreatic tail was possible only in 33 % of patients [33]. Another study reported incomplete pancreatic tail visualization in 32 % of cases [34]. Therefore, it is crucial to realize the possible limitations of transabdominal ultrasound with respect to visualizing the whole pancreatic tail.



▶ **Fig. 4** The pancreas body is measured over the superior mesenteric artery region from the leading edge to the trailing edge.

▶ **Fig. 5** In the splenic hilus, the pancreas tail is measured from the anterior edge to the posterior edge.

Nakao et al. [35] published a protocol for better visualization of the whole pancreatic organ that entails positioning the patient in a sitting position, having the patient drink 350 ml of liquid (mostly tea), and then waiting for the patient's stomach to fill in order to eliminate disturbing gas. By using this "special pancreatic ultrasonography" and taking more than 20 minutes for every investigation, they achieved a significantly higher sensitivity (92 %) compared to routine ultrasound (70 %) for detecting cysts (447 cysts in 186 patients). The improvement in cyst detection was significant for all parts of the pancreas but was more evident for the pancreatic head (97 % vs. 70 %) and tail (67 % vs. 27 %) compared to the body, body-tail, and uncinate process [35]. In our experience, visualization of the tail of the pancreas depends mainly on the examiner's experience. In order to achieve the most complete assessment of the pancreas, the examination should be carried out in the supine, left and right lateral, and standing positions. If qualitatively adequate and complete sonographic visualization of the pancreas is not achieved despite an adequate preparation and examination technique by an experienced examiner, a decision must be made as to whether to perform radiological cross-sectional imaging or endosonography, depending on the indication for the examination.

When assessing the pancreas, the size of the different parts (head, body, and tail) and their harmonic relation, contour, echogenicity of the pancreatic parenchyma, and the diameter of the pancreatic duct are evaluated [6].

Complete assessment of the whole pancreatic organ is essential for detecting and excluding a pancreatic pathology. Particular attention should be directed to ductal changes, which may be the result of aging processes of the parenchyma [1, 3] as well as early signs of chronic pancreatitis and especially neoplastic pancreatic lesions, including pancreatic ductal adenocarcinoma (PDAC) and its important differential diagnoses [36–40].

▶ **Table 1** What should you do when learning and performing ultrasound?

Anatomical structure	What should I do?
Pancreatic body	In the supine position, the pancreatic body is imaged in a transverse section. The standard section shows the splenic vein and the superior mesenteric artery. ▪ The pancreatic body is measured from the ventral contour to the dorsal contour. ▪ In the pancreatic body, the pancreatic duct is routinely assessed. The inside diameter is measured. Note: ▪ The pancreas is easier to see when the abdomen is bulged out. ▪ In mobile patients, the pancreas can also be examined while standing. ▪ Drinking still water can improve visibility in the case of disturbing gas in the stomach
Pancreatic head	After examining the pancreatic body, the transducer is moved slightly clockwise to the patient's right and tilted caudally in the transverse section, and the pancreatic head is adjusted. ▪ In this position, the transducer is rotated into the longitudinal section. ▪ The anteroposterior and transverse diameters are measured.
Pancreatic tail	The tail of the pancreas is located intercostally in the splenic hilum. When locating the tail of the pancreas, it is helpful to target the splenic vein, as this forms the dorsal border of the tail of the pancreas. ▪ The tail of the pancreas is measured from the anterior to the posterior contour or along its orthogonal axis. ▪ Attention is paid to whether the tail of the pancreas can be seen and whether it is enlarged. In this case, it is measured.

Pancreatic size and volume

The head of the pancreas is imaged in transverse and longitudinal sections. The transverse diameter and the anteroposterior diameter are measured at the head of the pancreas in its largest dimensions [6, 41–46]. The pancreatic body is viewed in a transverse section. The most reproducible and, therefore, reliable point is measured at the level of the superior mesenteric artery anteroposterior from the ventral to the dorsal contour [6, 42, 43, 45]. For the tail, the maximal orthogonal diameter is evaluated with the probe in the 10^{th} to 11^{th} intercostal space in the anterior axillary line [6, 13, 42, 43, 45].

Treiber et al. conducted a retrospective study establishing reference values for the pancreatic head, body, and tail based on 921 patients (443 males, 478 females, aged 41 ± 13 years old) without pancreatic disease. The pancreatic head and body were measured from ventral to dorsal, and the tail was measured perpendicular to the main axis of the pancreas. Normal values (5^{th} and 95^{th} percentile) were 2.2 ± 0.49 cm (1.5–3.1) for the head, 1.1 ± 0.32 cm (0.6–1.6 cm) for the body, and 2.1 ± 0.49 cm (1.4–3.0) for the tail. The craniocaudal diameter was not reported. Body height, weight, and BMI were positively correlated with pancreatic size, whereas age only showed a significant correlation with the pancreatic head and body size. Patients with chronic pancreatitis showed slightly but significantly larger measurements than the average population. Mean differences were 3 mm at the head, 3 (male) respectively, 4 (female) mm at the body, and 2 mm at the tail. They concluded that despite a statistically significantly enlarged pancreas size in chronic pancreatitis, the mean absolute values were still 5–95 % percentile in healthy adults. Therefore, the clinical value of pancreatic measurement for the differentiation of healthy or pathologic conditions remains unclear [42].

In the study by Pirri et al., 77 healthy subjects (25 males and 52 females, 56 ± 18 years) were analyzed regarding the biliopancreatic system. Patients were examined in a supine and left lateral decubitus position in epigastric longitudinal orientation, measuring the craniocaudal and anteroposterior pancreatic head diameter, and in transverse orientation, measuring the right-left and anteroposterior diameters. A mean value of 49 ± 10 mm [26–77] mm (mean ± SD [minimum-maximum] for the cranio-caudal pancreatic head diameter was found [41]. The antero-posterior diameter in a supine position was 23 ± 5.5 mm in females and 25 ± 5.3 mm in males.

A prospective study with 16 asymptomatic volunteers (8 males, 8 females; age 21 ± 2 years) was performed with a 1–5 MHz convex probe to evaluate sizes and to determine elasticity. The images were obtained with patients in a supine position in a transverse or slightly oblique transverse plane. Dimensions of the pancreatic head, body, and tail were recorded. The mean dimensions were reported as follows: 17 ± 3 mm for the head, 14 ± 4 mm for the body, and 14 ± 6 mm for the tail, with a significant correlation with age, height, and weight [47]. The study by Almutairi showed smaller pancreas dimensions for all three segments, therefore calling into question the existence of an established measurement method between different studies.

Khammas et al. aimed to determine baseline values in Malaysian adults. 408 participants were analyzed with abdominal US, and 294 were classified as normal. After an 8-hour fasting period, participants were positioned in a supine or lateral decubitus position. A 3.5 MHz probe was used. Measurements were taken using a high epigastric probe position in the antero-posterior direction. Values of 2.62 ± 0.53 cm for the head and 1.61 ± 0.49 cm for the body were measured. Due to the difficulty in assessing the pancreatic tail on the transverse scan, this study did not measure it. Increased diameters were found in patients with hepatobiliary disease [46].

In a Nigerian cohort, pancreatic measurements were performed to compare 150 diabetic and 150 matched non-diabetic persons [48]. They reported an anterior-posterior head diameter of 2.32 ± 0.22 cm, body diameter of 1.43 ± 0.19 cm, and tail diameter of 1.34 ± 0.20 cm in the non-diabetic controls.

In transverse computed tomography (CT) and magnetic resonance imaging (MRI) examinations, determination of the anterior-posterior and lateral diameters is considered standard [49], and the craniocaudal diameter is often neglected since it is only illustrated by reconstruction. One study showed a significant discrepancy between MRI and US measurements with smaller sizes using ultrasound for each pancreatic segment ranging from 14.4–43.3 % compared to MRI [43]. As has been shown by a study including measurement of the cranio-caudal pancreatic head diameter [41] and a comparison of measurements performed on US and MRI [43]: "The pancreatic head is larger than often assumed" [41].

Factors influencing interpretation

Physiological aging processes of the pancreas with initially focal and later during aging diffuse changes have to be differentiated from irreversible chronic inflammation and fibrosis [1, 3, 19]. An increase in diameter with inspiration has also been stated [50]. This may partly explain differences between measurement results of ultrasound and cross-sectional imaging methods carried out under more extended breath-holding inspiration maneuvers.

The influence of age [20, 25, 29, 30, 32] and gender [25, 46] on pancreatic size has been discussed in the literature. The organ size of the pancreas correlates to some degree with body weight and height [29, 51]. A positive correlation of pancreatic size with diabetes mellitus type 2 (DM) was shown, whereas a negative correlation with DM type 1 was demonstrated [9, 29, 48, 52]. However, conflicting results with a negative correlation with diabetes type 2 were shown in a Nigerian study [48]. The longer duration of diabetes mellitus was associated with smaller pancreas body and tail dimensions, while pancreas head dimension was not significantly affected by the duration of illness [48]. The pancreas enlarges in inflammatory diseases, including acute and chronic pancreatitis and neoplastic infiltration [42]. In patients with cystic fibrosis, the corpus and cauda may show atrophy with an enlarged pancreatic head with strong echogenicity [13]. The pancreatic size has also been described as smaller in protein deficiency syndrome, marasmus, and Kwashiorkor [29]. In summary, most studies state a larger pancreatic size in men than women and a decrease in pancreatic size during aging. However, no significant correlation between aging and sex was demonstrated in diabetics [48].

Reference values and documentation

Pancreatic head:

49 ± 10 (26–77) mm in (longitudinal plane, cranio-caudal measurement) [6, 41].

34 ± 8 (19–52) mm (right-left diameter) [6, 41].
23 ± 5 (14–39) mm (antero-posterior diameter) [6, 41, 45].
Corpus: 10–20 mm [6, 13, 45].
Cauda: 20–35 mm [6, 13, 45].

The size of the pancreatic head should be documented in at least two diameters. We recommend the documentation of all three dimensions reflecting examination quality. However, the benefit of absolute size measurements in the clinical routine remains an open issue.

Pancreatic Duct

The pancreatic duct should be identified and measured in all (mobile) patients. If this is not possible in the supine position, the examination should also be performed in the left lateral and standing positions ▶ **Fig. 6, 7**. The maximum diameter is measured from the inner-to-inner layer in the corpus and should be less than 2 mm [45]. The values in the pancreatic neck (between head and corpus) may be physiologically larger than 2 mm [19]. An increase in pancreatic duct diameter with aging was also demonstrated [3, 17]. It is essential to know that the diameter of the pancreatic duct will increase in about 50 % of healthy subjects when changing the position from supine to upright [53] and during inspiration [50] and secretin stimulation as used in magnetic resonance imaging (MRCP) of the pancreatic duct and rarely also in endoscopic retrograde cholangio-pancreaticography (ERCP) [54, 55]. However, pharmaceutical secretin preparations are no longer available on the market. Endosonographically, the Ductus Wirsungianus can be visualized regularly. The average diameter of the normal MPD was 1.7 mm, with an interquartile range of 0.9–4.3 mm [34]. In an MRI study, Wang et al. describe the diameter of the pancreatic duct in the pancreatic body as 1.57 ± 0.35 mm, with an age-related increase [56]. Beyer et al. described the average width of the pancreatic duct on MRI as 1.8 ± 0.96 mm [57].

Interestingly, the pancreatic duct was slightly wider after cholecystectomy: 2.1 ± 1.09 mm. This study also described an increase in the width of the pancreatic duct as part of the aging process. The authors considered a duct width of up to 3 mm normal in people up to 65 years of age and up to 4 mm in people over 65 [57].

Reference values and documentation

Pancreatic body: < 2 mm (age-dependent > 50 years old up to 2.5 mm).

Upper limit values in the pancreatic head, especially in the neck between the caput and corpus, may be up to 3 mm.

The diameter of the pancreatic duct should be measured in the pancreatic body in all patients with corresponding clinical questions. Consequently, the report should also mention if the pancreatic duct cannot be visualized.

Practical tips, tricks, and recommendations

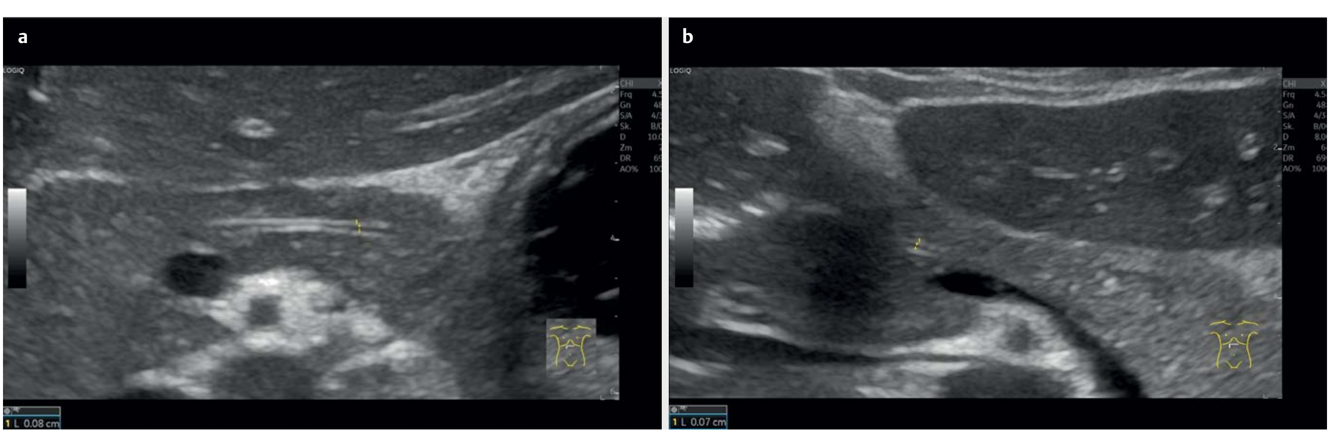
A review analyzing pancreatic duct imaging during aging was recently conducted [3]. The consensus of the pancreatic duct diameter of 3–2–1 mm for the head, body, and tail was further strengthened. Aging can lead to slight pancreatic duct dilatation without pathologic significance. However, a slight dilatation of the pancreatic duct may be associated with pancreatic pathology (early signs of PDAC) in nearly one-fourth of individuals [58]. The following age-adjusted reference values can be recommended: upper normal limit 2 mm for people < 50 years and 2.5 mm for people > 50 years. In patients with a pancreatic duct diameter of > 2 mm measured in the pancreatic body in a supine position, an underlying (obstructive) pathology, especially PDAC, needs to be excluded [3]. In geriatric [59, 60], palliative care [61, 62], and non-mobile patients in emergency care [63, 64], different questions need to be answered rather than measuring organ diameters, which are related to the specific conditions, complications of pancreatitis, and other pathologies [65–68].

Factors influencing interpretation

An increase in pancreatic duct size with aging was demonstrated [3, 17], and changes in diameter during changes of position, e. g., wider in upright body position compared to supine, were shown [53].

Echogenicity

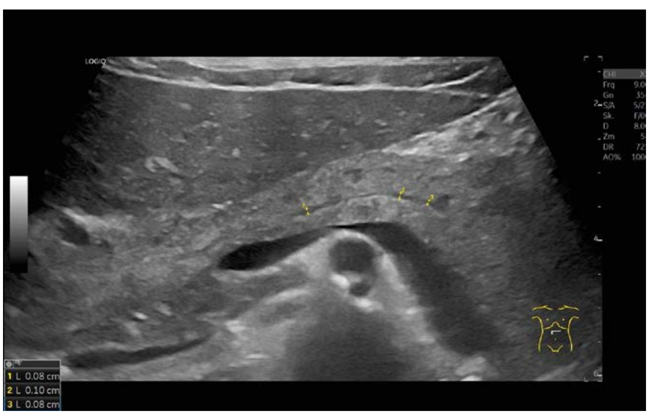
With the aging process, the parenchymal volume decreases, and fatty infiltration occurs. Focal areas of multiple fatty infiltration are



▶ **Fig. 6** The pancreatic duct is measured in the pancreas body near the pancreas head, and the measurement is performed at the inner contours (a, b).

hyperechoic and must be differentiated from pathological changes [1]. An increase in the echogenicity of the pancreatic parenchyma is shown with age [1, 3, 17, 32], whereas the BMI's influence on echogenicity remains controversial. Knowing that body weight usually increases during aging, such a correlation between BMI and echogenicity seems logical [25, 29, 32]. The pancreatic echogenicity can be compared to healthy liver parenchyma [69, 70]. Graduation of pancreatic echogenicity in comparison to the healthy liver parenchyma has been proposed by Marks et al. [69] and Worthen and Beabeau [70]. However, this method is very subjective, especially in obese patients or subjects with hepatic diseases where alterations in the liver parenchyma are present. This comparison is not generally recommended due to significant variations during aging and the high prevalence of pancreas and liver metabolic changes.

A Korean study retrospectively calculated the pancreato-perihepatic fat index for 286 patients [71]. This fat index was significantly higher in subjects with metabolic syndrome and was strongly associated with waist circumference.



▶ **Fig. 7** Slightly hyperechoic pancreas with slightly less echogenic ventral attachment to the pancreatic head and well visible, very narrow pancreatic duct. The course of the pancreatic duct is marked by the measurements.

In the literature, two parts of the pancreatic head's "normal" echogenicity are described [72]. A demarcated hypoechoic area within the pancreatic head compared to the rest of the pancreas can often be observed in younger and healthy (more often in female) subjects correlating to the embryological ventral portion ▶ **Fig. 8** [72]. Two different embryologic origins explain the feature. A prevalence of 28 % in an ultrasound study among 32 healthy volunteers has been published [73]. A 22 % prevalence of hypodense portions of the head is stated for CT examinations [74]. Another CT study revealed a 3.2 % prevalence of uneven fatty infiltration that has to be differentiated from focal lesions [75]. Therefore, a well-demarcated sonographically hypoechoic region within the pancreatic head without obstruction of the MPD is a normal variant and has to be differentiated from abnormal focal lesions. This finding is probably related to significant fat quantities in the interlobular septa and acinar cells of the dorsal segment [72], and a change over time has been reported [1, 3].

Factors influencing interpretation

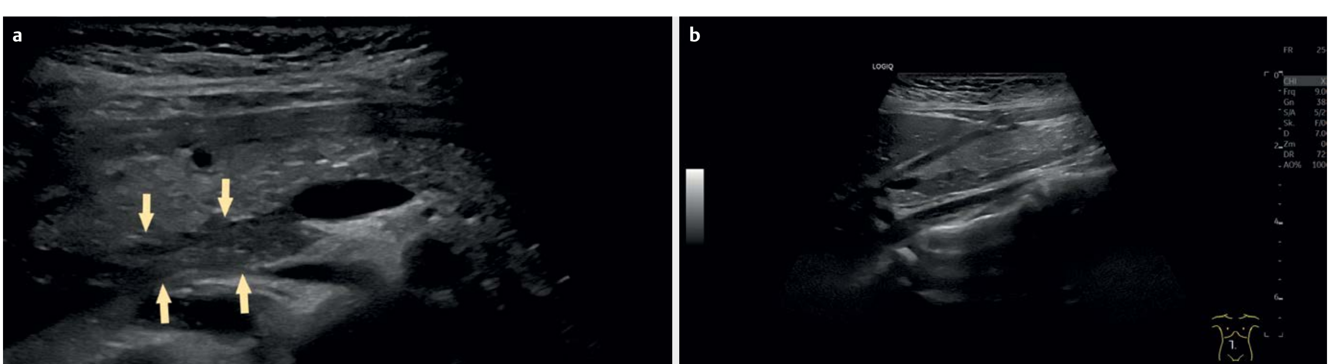
An increase in echogenicity with age has been shown [3, 17, 32], whereas the influence of BMI on echogenicity remains controversial (no correlation [32]; positive correlation [25, 29]).

Pancreatic variations

There are various pancreatic appearances and shapes, some of which are considered normal and others pathological.

Mobile pancreas

A mobile pancreas is a common phenomenon not often recognized in the daily routine ▶ **Fig. 9** [44]. Significant movement of the pancreatic head in relation to the aorta and spine can be observed by changing the patient's position from supine to left lateral. Knowledge of this phenomenon is important for the correct interpretation of endoscopic ultrasound examinations, often with the head and tail forming a "U" around the transducer. Both parts of the organ can be seen on one image. The moving distance is correlated to age and sex (especially in young healthy females) and is re-



▶ **Fig. 8** Pancreatic head transverse (**a**) and longitudinal (**b**). Dorsally, the embryological ventral part is demarcated. This is crescent-shaped, relatively smoothly bordered to the rest of the pancreatic head, and less echogenic than the rest of the pancreatic head. This is a physiological finding.

duced in the presence of chronic pancreatitis. No association has been reported between the moving distance, body mass index (BMI), and splenic size [44].

Normal anatomical variants of the pancreas

Contour bulges

Nature of changes: Lobus-like contour protrusion on the pancreatic head anteriorly, dorsally, or laterally. **Description**: Bulging of the contour, same echogenicity as the rest of the parenchyma. **Meaning**: Can be confused with pseudo-mass and tumors.

"Tuber omentale" [76]

Nature of changes: Contour bulge. **Description**: Bulging/prominent anterior surface of the pancreatic body. **Meaning**: Can be confused with enlargement of the pancreatic body and pseudo masses.

Echogenicity

The nature of changes has been described above.

Congenital changes in the pancreas

Fusion anomaly

Nature of changes: Pancreas divisum [77–81]. **Description**: Failure of fusion of the pancreatic duct between the ventral and dorsal bud of the pancreatic head during embryonic development. The connection between the two parts of the duct is completely or incompletely missing. The larger part of the pancreas - the dorsal bud (dorsal part of the pancreatic head, pancreatic body, and pancreatic tail) drains into the duodenum via the small minor papilla. The small part - the ventral bud drains into the duodenum via the major papilla. Sonographically, a pancreas divisum is suspected if the pancreatic duct is accentuated or dilated in the dorsal bud of the pancreatic head, the pancreatic body, and pancreatic tail and feeds into the duodenum at the level of the pancreatic neck and the gastroduodenal artery. In contrast, the pancreatic duct is small in the ventral bud of the pancreatic head.
Meaning: The ostium of the minor papilla may not be sufficient for the pancreatic duct from the dorsal bud, and there may be congestion of the pancreatic duct with recurrent episodes of pancreatitis and the development of chronic pancreatitis. In this case, endoscopic interventions on the minor papilla with pancreatic sphincterotomy are indicated. Diagnosis is usually made by magnetic resonance cholangiopancreaticography (MRCP) or endoscopic ultrasound.

Developmental (rotation and migration) anomalies

Nature of changes: Pancreas anulare [76, 79, 82–88]. **Description**: Incomplete rotation of the ventral bud. The pancreas either completely or incompletely surrounds the descending duodenum. Sonographic diagnosis is difficult. As a rule, the diagnosis is made by MRI. By knowing the suspected diagnosis, the diagnosis can also be made on radial EUS if care is taken to ensure that the pancreas completely surrounds the duodenum. CT can also be used to diagnose the annular pancreas, but an MRI examination that does not expose the patient to radiation would be preferred. In the prenatal period and in childhood, the "double bubble sign" has been described. This describes dilatation of the stomach and duodenum due to duodenal stenosis. A "crocodile jaw" configuration should raise suspicion of an incomplete annular pancreas. A portal annular pancreas is an anomaly in which aberrant pancreatic tissue completely surrounds the portal vein and/or venous confluence. **Meaning**: An annular pancreas can lead to duodenal stenosis. Other complications include post-bulbar ulcerations, pancreatitis, and biliary obstruction. In childhood, pancreas anulare is often observed in association with other congenital anomalies (esophageal atresia, imperforate anus, heart defect, Down's syndrome). If the diagnosis tends to remain undetected until adulthood, these are more likely to be incidental findings on imaging in the case of duodenal stenosis and gastric retention.

Branching anomaly

Nature of changes: Pancreas bifidum – tail fish pancreas [89–92]. **Description**: Branching anomaly of the pancreas defined by its duplication in the pancreatic tail. **Meaning**: Its clinical impact is not well established.

Parenchymal development anomalies

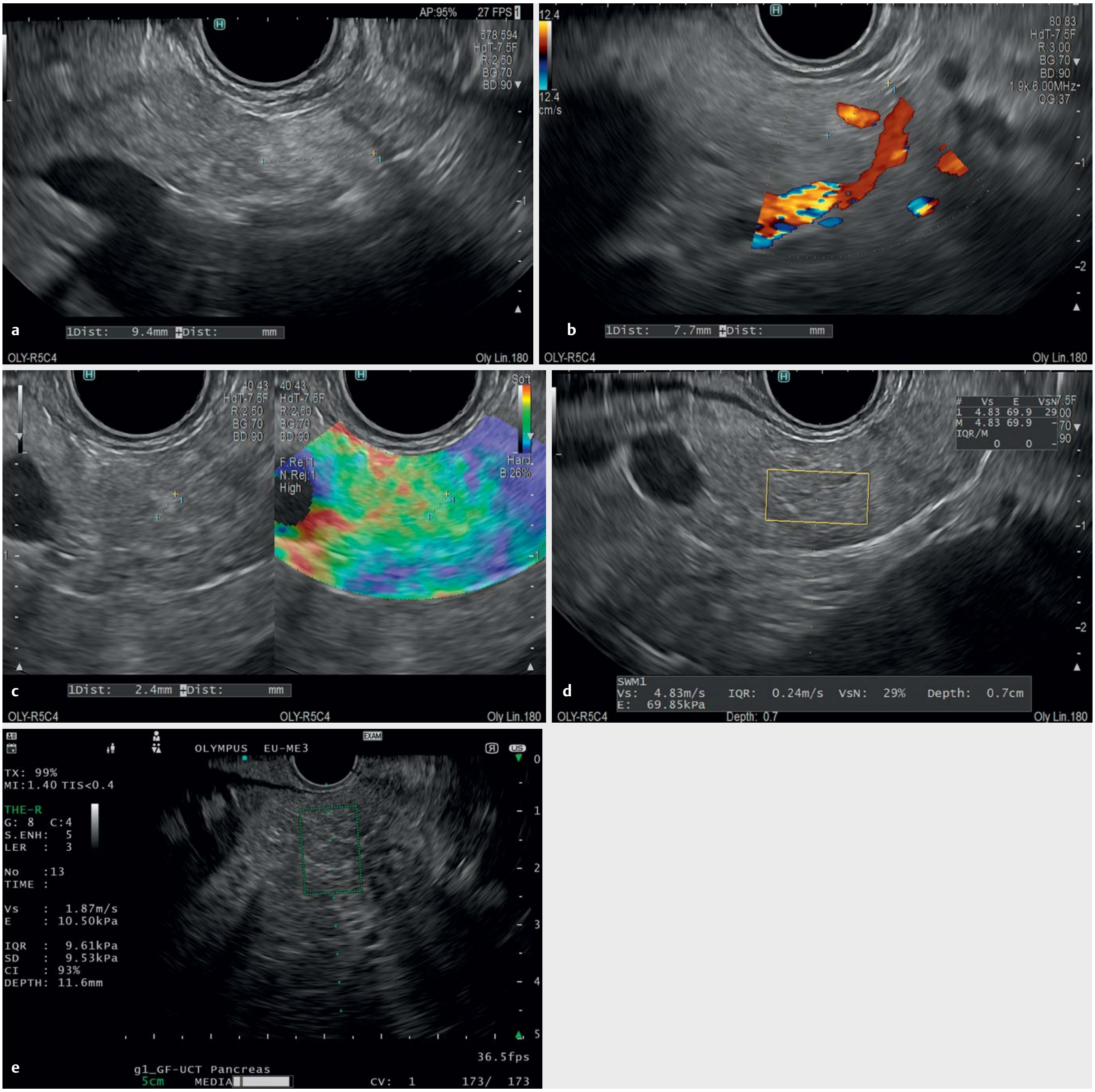
Nature of changes: Incomplete aplasia/hypoplasia/aplasia of parts of the pancreas.
Description: Parts of the pancreas are missing. **Meaning**: Exocrine and endocrine insufficiency may occur depending on the extent of aplasia. The absence of parts of the pancreas on ultrasound may be misinterpreted as poorly adjustable or "air-superimposed" pancreas.

A short introduction to pancreatic elastography

Ultrasound elastography (USE) of the pancreas allows pancreatic tissue stiffness assessment. A prerequisite of all kinds of elastography is the complete visualization of the gland. Two main types of USE are used: Ultrasound strain elastography (SE) and ultrasound shear wave elastography (SWE). Both techniques can be applied endoscopically or transabdominally [93, 94].

Comparatively little is known about the elastographic properties of the pancreatic parenchyma [40, 95, 96]. Previous published studies on pancreatic stiffness are limited in number and are heterogeneous in terms of study design, definition of health status, examination technique (transabdominal versus endosonograph-

▶ **Fig. 9** Mobile pancreas. In the left lateral position, the pancreas shifts to the left. The pancreatic head is on the left lateral side of the aorta.



▸ **Fig. 10** Endoscopic ultrasound images are shown with focal fatty infiltration (between marker) and other degenerative signs (**a**). Color Doppler ultrasound reveals the supplying splenic vein branch (**b**). Different elastographic methods are shown in the same patient with a small focal lesion (in between markers) being soft using strain imaging (**c**). Shear wave speed measurement with higher values (70 kPa) than normal is shown in (**d**) in comparison to a normal pancreas in (**e**) with 10.5 kPa.

ic), ethical aspects (especially invasive endosonographic examination of healthy subjects), examination technique used (transient elastography, point shear wave elastography, 2D and 3D shear wave elastography, strain imaging with histogram analysis, and all of the mentioned techniques specifically and separately analyzed for the transabdominal versus the endosonographic approach) [97, 98]. A combined comparison of data and a summary of reference values up to now is not possible ▸ **Fig. 10**. In addition, the different characteristics of the pancreatic head, body, and tail, as well as the different organ volumes, aging processes, and various confounding factors, must be considered. We also refer to a separate publication on virtual touch imaging quantification elastography in measurements of the pancreas [95].

A short introduction to contrast-enhanced ultrasound

Contrast-enhanced ultrasound (CEUS) can assess the vascularization of the pancreatic parenchyma and focal lesions using the transabdominal and endosonographic approach. CEUS is performed using the ultrasound contrast agents SonoVue® and Sonazoid® with a device-specific low mechanical index of < 0.3. In the pancreas, the arterial phase starts at 10–20 seconds and lasts until 35–40 seconds after injection of the ultrasound contrast agent. Peak enhancement occurs at 22–26 seconds. In the parenchymal phase, enhancement decreases progressively [99]. Critical clinical applications are the detection of pancreatic necrosis, the differentiation between the usually hypoenhancing PDAC and the diverse group of iso- and hyperenhancing solid pancreatic lesions, and the characterization of septa and mural nodules in pancreatic cystic lesions [100, 101].

Conclusion

In conclusion, complete assessment of the pancreas should be targeted in every ultrasound examination of the abdomen, and it is possible in the vast majority of cases if the examination technique is appropriate. The size of the pancreatic head should be documented at least in two diameters. We recommend the documentation of all three dimensions at least during the learning curve since "the pancreatic head is larger than often assumed" [41], and the pancreas is mobile during body position changes [44]. The diameter of the MPD should be documented in the pancreatic body in all patients, as even a slight increase can be an important indication of early PDAC [3, 39, 40]. Particular attention should be directed to the aging processes of the parenchyma [1, 3]. Due to lipomatous transformation, the echogenicity of the parenchyma increases with the aging process and BMI, and this process often starts focally.

Conflict of Interest

The authors declare that they have no conflict of interest.

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