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ORIGINAL ARTICLE

Diffusion-Weighted MR Imaging of Normal Pancreas in Children and Adults; Relation of Apparent Diffusion Coefficient Values with Age and Gender

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Abstract

Introduction: The objective of this study was to evaluate the healthy pancreas with diffusion-weighted imaging (DWI) in children and adults and demonstrate the changes of apparent diffusion coefficient (ADC) values related to age and gender.

Methods: Eighty-five patients, who did not have pancreas disease, were included in the study. The patients were divided into four groups according to their ages (0–20 years; 21–40 years; 41–60 years; ≥61 years). Diffusion-weighted images were obtained in the axial plane, with three different b-values (b=0; b=50 and b=400 s/mm^2) and ADC maps were calculated automatically. On the ADC maps, three separate ADC values were calculated for each region (head, body, and tail) with the free-hand technique using the "region of interest". Then, the mean values were calculated. The mean ADC values of the pancreatic head, body, and tail were used for the calculation of the total ADC value. The effect of age and gender on ADC values was determined by one-way ANOVA analysis and independent sample t-test, respectively.

Results: The mean pancreatic total ADC value was higher in 0–20 years and ≥61 age groups compared to other age groups. In addition, the ADC values of the pancreatic head in the 0–20 age group were found to be statistically significantly higher compared to those of 21–40 and 41–60 age groups. There was no correlation between mean pancreatic total, head, corpus, and tail ADC values and gender.

Discussion and Conclusion: The results of this study demonstrate that age has an effect on pancreatic ADC values, nevertheless gender has no effect on ADC values. The mean ADC values by age and gender may be useful in diagnosing diseases and can be used as a reference for the future studies.

Keywords: Age; diffusion-weighted imaging; gender; pancreas.

Diffusion-weighted imaging (DWI) is a technique used in the magnetic resonance imaging and it enables to visualize the physical properties of the thermal movement of the water molecules in the biological tissues[1,2]. The cellularity and different composition of the tissues affect the free movement of water molecules, which is expressed with the apparent diffusion coefficient (ADC)[3].

The DWI was first used for the visualization of the acute stroke and tumors in the central nervous system[4-6]. Recently developed techniques enabled the usage of the DWI and ADC measurements in the abdominal organs[7-10].

Studies had demonstrated that DWI may be useful in the diagnosis of pancreatic disorders such as acute and chronic pancreatitis and malign pancreatic masses. While tissue

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edema and increased diffusion due to the perfusion anomalies were observed in acute pancreatitis, diffusion was restricted and ADC values decreased in some malignancies and chronic pancreatitis[7,11,12].

ADC values can be influenced by magnetic field strength, motion, pulse sequence types, and b-values. Water and fat contents of tissues can also affect diffusion properties[13]. Atrophy, fatty degeneration, and fibrosis, which develop in the pancreas with aging, were demonstrated in previous studies with pathological and several imaging methods[14-20]. The objective of this study was to evaluate the healthy pancreas with DWI in children and adults and demonstrates the changes of ADC values related to age and gender.

Materials and Methods

Patient Selection

The study was approved by the Local Ethics Committee. This study complies with the principles of the 2008 Declaration of Helsinki and was approved by the local ethics committee of Harran University Faculty of Medicine (Approval date and number: May 19, 2019, Session 5 21081). The images of 248 patients, who underwent MRI examination of the upper abdomen between January 2018 and April 2019, were evaluated respectively. After the exclusion of the patients, who had diseases like a mass lesion in the pancreas, diabetes mellitus, ascites, and chronic liver disease, which may affect the pancreas, 85 patients fulfilled the inclusion criteria and were enrolled in the study. About 43.5% of the patients (n=37) were males and 56.5% were females (n=48). The mean age was 41.86±20.81 years (0–85 years). The patients were divided into four groups according to their ages: 0–20 ages (n=18); 21–40 years (n=23); 41–60 years (n=24), and ≥61 years (n=20).

MRI Protocol

All MRI examinations were performed with a 3T MRI device (Magnetom Skyra; Siemens Medical Solutions, Erlangen, Germany). A combination of an 18-channel phased-array body coil which was placed on the abdomen while the patient was in the supine position, and a 32-channel phased-array spine coil was used for the signal detection. The routine upper abdomen MRI protocol in our institute is as follows: Coronal T2-weighted Half-Fourier acquisition single-shot turbo spin-echo (T2-HASTE), repetition time (TR), 1400 ms; echo time (TE), 102 ms; field-of-view (FOV), 372 mm; slice thickness, 5.0 mm; phase FOV, 1.00), axial fat suppression T2-HASTE, TR, 1400 ms; TE, 95 ms; FOV, 380 mm; slice thickness, 5 mm; phase FOV, 0,78), axial T1-weighted phase and opposed phase spin-echo sequence, TR, 171 ms; TE1, 1,23 ms (TE2), 2,46 ms; FOV, 380 mm; slice thickness, 5 mm; phase FOV, 81,3). At the end of the examination, 0.1 ml/kg gadobutrol (Gd-BT-DO3A; Gadovist, Schering, Germany) was added to 10 ml saline solution and dynamic contrast images were obtained by using volumetric interpolated breath-hold examination (VIBE) sequence.

Diffusion-weighted images were obtained in the axial plane, with single-shot echo-planar spin-echo sequence and three different b-values (b=0; b=50 and b=400s/mm2). The imaging parameters were as follows: TR, 5000 ms; TE, 45 ms; FOV, 380 mm; slice thickness, 5 mm; phase FOV, 80.6. The examination was performed during normal breathing. For measurements of ADC values, all data were digitally transferred to the syngo.via software package (version VA11A, Siemens Healthcare, Erlangen, Germany).

Analysis of the Images

The magnetic resonance images were assessed by O.D. who had a 10-year experience in the abdominal radiology. The region, which is at the medial of the superior mesenteric artery and vein, was defined as the pancreatic head; the region between the superior mesenteric artery/vein and the left lateral wall of the aorta was defined as the pancreatic body and the remaining region was defined as the pancreatic tail[13]. The measurements were performed on the axial ADC maps, while three ellipsoid regions of interests (ROI) with a diameter between 0.20 and 0.25cm^2 were placed on each region of the pancreas (Fig. 1). ADC values were cal-

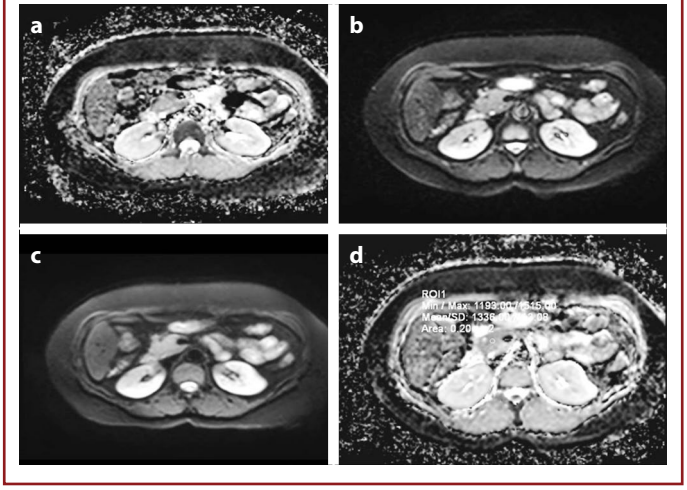

Figure 1. A 37-year-old female patient. A non-breath hold axial DWI obtained with three different b values at the level of the pancreas head: **(a)** b=0, **(b)** b=50, **(c)** b=400 s/mm^2, and **(d)** An ADC map calculated with all b values and placement of ROI on the pancreas head.

culated from the ROIs, by dividing the signal intensity by 1000 to get the values in terms of ADC×10^{-3} mm^2/s. Measurements were preferably done in areas, where the main pancreatic duct and vascular structures were not found. The mean of three measurements was used to calculate the mean ADC values for the head, body, and tail. The ADC values of the total pancreas were calculated with the sum of the mean ADC values of three regions of the pancreas.

Statistical Analysis

The statistical analysis was performed with the software package SPSS v24.0 (SPSS Inc, Chicago, IL). The results were expressed as mean±standard deviation. The normal distribution of the variables was analyzed with visual (histogram and probability plots) and analytical methods (Kolmogorov–Smirnov). Intergroup comparison was done with the independent samples t-test and one-way ANOVA test for the parametric variables. The post hoc analysis of the variables with homogeneous distribution was performed with the Bonferroni test. The categorical variables analyzed with Pearson's Chi-square test. P<0.05 indicated a statistically significant difference.

Results

Pearson's Chi-square analysis showed that gender distribution was similar in the age groups (p=0.762, Table 1).

The ADC measurements of the total pancreas and the pancreatic head, body, and tail were recorded for all patients in each age group. The one-way ANOVA analysis showed that there was a significant difference between the mean ADC value of the total pancreas and mean ADC values of the pancreatic head, while there was no significant difference between mean ADC values of the pancreatic body and tail (Table 2). Regarding the post hoc Bonferroni test, the mean pancreatic total ADC value varied significantly between the 0–20 and 41–60 age groups and between the 41–60 and ≥ 61 age groups (p=0.036) (Table 2). There was no statistical significance between other age groups (p>0.05). The post hoc Bonferroni analysis showed also that there was a significant difference between 0–20 and 21–40 years groups (p=0.024) and between 0–20 and 41–60 years groups (p=0.002) for the mean ADC value of the pancreatic head. There was no statistically significant difference between other age groups (p>0.05). Pearson's correlation analysis did not show any significant relationship between the age and the ADC values of the total pancreas and the pancreatic head, body, and tail (p>0.05).

Finally, the subjects were compared according to the gender groups with the independent samples t-test for the mean ADC values of the total pancreas and the pancreatic head, body, and tail. These analyses did not display any statistically significant difference (Table 3).

Table 1. Sociodemographic distribution of cases

	Male (n=37)	Female (n=48)	[a]p
Year (n, %)			
0-20 age	8 (21.6)	10 (20.8)	
21-40 age	12 (32.4)	11 (22.9)	0.76
41-60 age	9 (24.3)	15 (31.3)	
≥61 age	8 (21.6)	12 (25)	

[a]Pearson's chi-square test; n= number of cases.

Table 3. Comparison of results according to gender groups

ADC values (×10^{-3} mm^2/s) Mean±SD	Male (n=37)	Female (n=48)	[a]p
Pancreas head	1.23±0.12	1.2±0.08	0.15
Pancreas body	1.2±0.13	1.21±0.11	0.72
Pancreas tail	1.2±0.11	1.19±0.1	0.74
Total pancreas	1.21±0.09	1.20±0.07	0.56

[a]: Independent samples t-test; Mean±SD: Mean±Standart deviation; ADC:Apparent diffusion coefficient. n= number of cases.

Table 2. Comparison of total pancreatic ADC, pancreatic head, body and tail sections ADC measurements of age groups

ADC (× 10^{-3} mm^2/s) *Mean±SD	0-20 age (n=18)	21-40 age (n=23)	41-60 age (n=24)	≥61 age (n=20)	[a]p
Pancreas head	1.28±0.1	1.19±0.07	1.16±0.08	1.23±0.12	0.02
Pancreas body	1.23±0.11	1.19±0.11	1.15±0.10	1.25±0.14	0.052
Pancreas tail	1.21±0.13	1.18±0.08	1.16±0.09	1.23±0.12	0.149
Total pancreas	1.24±0.08	1.19±0.05	1.16±0.06	1.24±0.1	0.002

[a]: One-way ANOVA Test; *:Measurements are given as mean±standard deviation; ADC: Apparent diffusion coefficient; n=number of cases.

Discussion

The principle of DWI is based on the unrestricted movement of water in tissues at the cellular level. The diffusion of water molecules is affected by the physicochemical properties of tissue, perfusion, cellular density, integrity of cell membranes in the tissue, and the presence of macromolecules[21].

In this study, we investigated the diffusion properties of the healthy pancreas and their correlation with age and gender. To the best of our knowledge this is the first paper that evaluate DWI of children and adults healthy pancreas with 3T. The assessment of the sociodemographic characteristics of the patients showed that the gender distribution was homogeneous among the groups. In the present study, we did not find any significant relationship between the gender and the mean ADC values of the total pancreas and the pancreatic head, body, and tail. In a study conducted by Ma et al.[22] there was no significant relationship between average pancreas ADC values and gender, similar to our study. In another study conducted by Herrman et al.[23] the mean pancreas ADC values were found to be higher in female compared to male. Body mass indexes (BMI) of the patients were not examined in our study and in the two studies mentioned. Body mass index of patients may affect the amount of components of the pancreas that affect diffusion, such as fat and water content[13]. The fact that BMI was not examined may have been effective in different results between studies. However, we determined a significant difference between the age groups for the ADC measurements obtained from the pancreatic head. On the other hand, there was no statistically significant difference between the ADC values obtained from the pancreatic body and tail regions. The mean ADC values of the pancreatic head were 1.28±0.1, 1.19±0.07, 1.16±0.08, and 1.23±0.12×10^{-3} mm^2 for the age groups 0–20 years, 21–40 years, 41–60 years, and ≥61 years, respectively. Pancreas originates from the ventral and dorsal pancreatic buds, which merge in the early embryonic period. While the ventral part of the pancreatic head, body, and tail originate from the dorsal bud, the dorsal part of the head originates from the ventral bud[24]. Anatomic research showed that there are different cell components; the pancreatic head contains more high-density acinar and low interlobular fat, and the body and tail contain more Langerhans islets and fat[24,25]. The high ADC value of the pancreatic head, especially in the 0–20 years age group might depend on the presence of the developing pancreatic tissue and different tissue composition. Another reason for high pancreatic head ADC values in children and young adults may be the use of 3T MRI. In a study performed by Barral et al.[26] to determine the normal pancreas ADC values, the pancreas was divided into four separate part and ADC values were obtained in 1.5T and 3T devices, while similar ADC values were obtained in all pancreas parts at 3T, the ADC value of the tail part was found to be lower at 1.5T. In this study, only b=0 value was used to obtain ADC values. In addition, the fact that patients with pancreatic atrophy, fat replacement, BMI> 25, and patients younger than 19 years old were not included in the study may explain the different results from our study. Schoennagel et al.[27] measured ADC values of the pancreatic head, body, and tail at different b-values and found out that ADC values were higher in the pancreatic head similar to our study. In the present study, the mean ADC value of the total pancreas was higher in the 0–20 and ≥61 year age groups compared to other groups. The mean ADC values of the total pancreas were 1.24±0.08, 1.19±0.05, 1.16±0.06, and 1.24±0.1×10^{-3} mm^2 in the age groups 0–20 years, 21–40 years, 41–60 years, and ≥61 years, respectively. Hermann et al.[23] determined a negative correlation between the ADC values and the age and found that the global ADC values of the pancreas were higher in children similar to our study. However, Ma et al.[22] could not determine any correlation between the pancreatic ADC values and the age and gender. Patients younger than 20 years old were not included in this study and ADC values were obtained without dividing the pancreas into sections. In our study, the total ADC values were high in the ≥61 years age group. Fatty atrophy, lobulation, and decrease in the number of acinar cells are observed in the pancreas with age. In addition, with age, periductal fibrosis and dilatation are observed in the main pancreatic duct and canalicular structures in the pancreas. Decreased cell count and increased lobulation can lead to increased extracellular space[28]. This may lead to an increase in diffusion and therefore mean ADC values may increase in ≥61 years age group. Different results between the studies may have been affected by factors such as the magnetic field strength of the devices used, different b values used in DWI, imaging technique, and different number of patient groups. In 1.5T, 150, and 800–1000 s/mm^2 b values are recommended for lesion characterization and 150, 400–500, and 800–1000 s/mm^2 b values for pancreas parenchyma abnormalities. It is recommended that at least one b value be 100 s/mm^2 to eliminate the perfusion effect and at least one b value should be equal to or <1000 s/mm^2 to avoid low signal-noise ratio (SNR)[29]. We used b=0, b=50 and b=400 s/mm^2 values in our study. It is stated that DWI

examinations obtained with free-breathing technique are located between the SNR-limited breath-hold technique and the respiratory-triggered technique, which extend the duration of the examination[30]. Free-breathing technique is thought to be less effective in detecting small lesions and determining the heterogeneity of lesions, but it is useful in qualitative and quantitative evaluation of DWI examinations of large organs[31]. In this study, we performed the free-breathing technique to evaluate the DWI of the pancreas and measure the quantitative ADC values.

Limitations of Our Study

Although the b values could not be intervened due to the retrospective nature of the study, the b values were within the acceptable range. Since all measurements were made by a single radiologist, there was no inter-reader agreement. Another reason for limitation is that patients' BMI information cannot be accessed from the records.

Recently, DWI has increasingly become a part of MRI examination. Regarding the pancreas, it is useful in the lesion characterization, diagnosis of the acute, and chronic pancreatitis. The increasing understanding of the effects of the age, gender, and different parts of the pancreas on the ADC values of the healthy pancreas may increase the efficiency of the diagnosis.

Ethics Committee Approval: This study complies with the principles of the 2008 Declaration of Helsinki and was approved by the local ethics committee of Harran University Faculty of Medicine (Approval date and number: May 19, 2019, Session 5 21081).

Peer-review: Externally peer-reviewed.

Authorship Contributions: Concept: O.D.; Design: O.D., A.D.; Data Collection or Processing: O.D.; Analysis or Interpretation: O.D., H.K.; Literature Search: O.D.; Writing: O.D.

Conflict of Interest: None declared.

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