

# How to improve image contrast of hepatic CECT scans in children

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## Abstract—

**Introduction.** Liver tumors are clinically evaluated using contrast enhanced computed tomography (CECT). For children, this type of CECT usually consists of two scans, one in the arterial phase, and one in the portal-venous phase. In our institution, the portal-venous scan is not always of sufficient quality, especially in small children. The inadequate contrast between hepatic vascular structures and the liver parenchyma is thought to be secondary to differences in hemodynamics compared to adults. Here, we describe relationships between CECT scan parameters, scan quality and scan timing in children, resulting in insufficient quality of the scan. These relationships cannot necessarily be described mathematically. We aim to improve the scan protocol based on these relationships.

**Methods & materials.** Data from 55 CT scans of 40 pediatric patients was acquired at our institution. An experienced radiologist scored the quality of each scan (bad/mediocre/sufficient/good) and estimated the timing of the portal-venous phase (too early/good/too late). A histogram analysis was performed, to investigate relationships between different parameters such as age, weight, bolus concentration, flow rate, and the qualitative measures of scan quality and timing.

**Results.** A significant number of scans with a low quality score were made of children aged 5 or younger, and all scans that were made too early appear in the same category. Most scans scored as ‘bad’ are of patients who received less than 1.4 ml contrast agent per kg body weight. All bad scans occur with patients with a flow rate smaller or equal to 3 ml/s.

**Conclusion & Discussion.** Based on this data, we recommend to increase the concentration of the administered contrast for liver tumor CT scans in all children to 2.5 ml/kg or higher, possibly introducing a weight or age dependence. This recommendation can be used to change the scan protocol, but effects of this change should be monitored closely.

## I. INTRODUCTION

COMPUTED tomography (CT) is a common tool for imaging of pediatric cancer patients. Specifically, children with liver cancer are often imaged using CT, to map the hepatic vascular structures, and to investigate their relation to the tumor. Imaging of vascular structures in the liver is often done using contrast enhanced CT (CECT). This method uses a contrast agent which is injected into the patients bloodstream. The X-rays that are used for CT imaging are attenuated more strongly by the contrast agent than by the surrounding tissue, resulting in high image contrast between blood vessels and the liver parenchyma, which allows for clear visualisation of vascular structures. Insight into vascular structures is of utmost importance for surgical planning, so that the hepatic vascular structures can be saved as much as possible when removing liver tumors during surgery.

Hepatic CECT acquisition are abdominal 3D acquisitions. The full field of view is usually scanned twice. The first

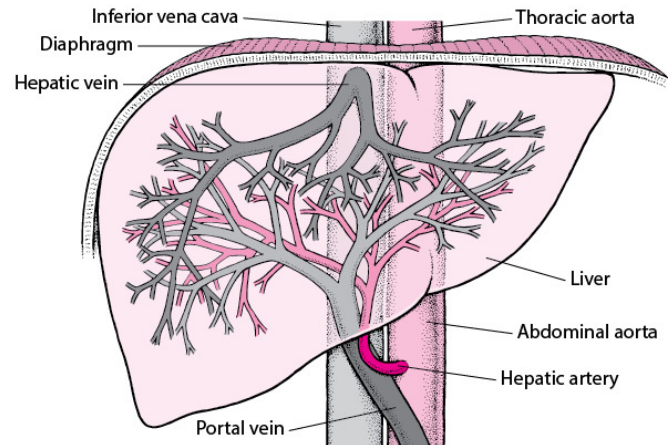


Fig. 1: Schematic overview of the blood supply of the liver [2]. Inflow from the hepatic artery is highlighted in the arterial phase, while inflow from the portal vein and outflow through the inferior vena cava is highlighted in the portal venous phase.

phase is the arterial phase, where the contrast bolus mainly flows through the hepatic artery. This accounts for 20-25% of the blood supply of the liver. The second phase is the portal-venous phase. In this phase the bolus enters the liver through the portal vein, which accounts for the other 75-80% of the liver blood supply [1]. This phase also highlights the outflow of blood through the inferior vena cava. Fig. 1 shows a schematic overview of the blood supply of the liver.

Many factors influence the scan quality, such as contrast concentration and flow rate, as well as patient-specific factors such as age, weight and hemodynamics.

**Contrast concentration:** If the concentration of iodine in the blood of the patient increases, attenuation of X-rays increases as well, and with it the contrast between the blood vessels and surrounding tissue. However, iodine concentration cannot be increased indefinitely. Iodine is hard to break down in the kidneys, and is a common cause of nephropathy [3]. Usually, iodine dose and concentration is adjusted to the patient body weight [4–13]. Sometimes other criteria are used, such as the body mass index [11], the lean body weight [12], or the body surface area [13, 14] of the patient.

**Flow rate:** The flow rate or injection speed also influences the contrast quality. When the flow rate is high, the bolus length will be short, resulting in a shorter temporal window [15]. With arterially perfused organs, a slower injection speeds results in a delayed peak enhancement [10]. However, since the blood supply of the liver originates from both the hepatic

arteries as the portal vein, this is not the case for the liver [16, 17].

Just as bolus concentration, flow rate is limited. Cannulas come in different sizes, and each size allows for a different flow rate [18]. The cannula size is based on the size of the access vein, with younger patients usually having smaller veins [18, 19].

*Portal-venous scan delay:* After contrast is administered, the image intensity in the descending aorta is monitored. When this intensity reaches a certain threshold, a timer starts, to be able to start the scans after certain delay times, which are prescribed in the scan protocol. Applying the correct portal-venous scan delay is essential, because the portal-venous scan must be acquired when the contrast between the veins and the parenchyma is optimal. The optimal scan delay partly depends on the flow rate [17]. For adults, a fixed scan delay is usually used, irrespective of physical parameters [6, 20, 21]. Research shows however that it would be better to vary scan delays for children with different physical parameters, such as age or weight [5, 6, 19, 21].

Currently, the quality of the CECT scans in children, especially of the portal-venous phase, is not always sufficient in our institution, due to low contrast between the hepatic vascular structures and the liver parenchyma. The originally used protocol only takes into account the patient age to determine the used flow rate and concentration of the contrast agent. The portal-venous scan delay was the same for all patients. Recently, the protocol has been changed, such that the concentration, flow rate and portal-venous scan delay depend on the patient body weight.

Previous research has been done with data from our institution to find a formulaic relationship between parameters and scan quality [22], but more research had to be done to come with concrete recommendations to improve the scan protocol. During this research, we try to find relationships which cannot necessarily be mathematically described, to investigate what improvements on the protocol can be applied to improve the scan quality. This research is based on the following two research questions:

- Based on retrospective data analysis, which parameters have a correlation with low image quality?
- How can this information be used to improve the scan protocol?

## II. MATERIALS & METHODS

### A. Acquisition

1) *Patients:* Scans for 40 pediatric patients were used during this research. These were 22 male patients (age  $7 \pm 6$ ) and 18 female patients (age  $6 \pm 7$ ). These patients received a multi-phase CECT scan, including at least the arterial and portal-venous phase. These scans were performed at the Wilhelmina Children's Hospital in Utrecht between January 2017 and March 2022. Some children received multiple scans, resulting in 55 scans to be analysed.

2) *Scan parameters:* All patients were scanned on a helical CT scanner (Somatom Force, Siemens Healthineers AG, Erlangen, Germany) version Syngo CT VA50A (2016), Syngo

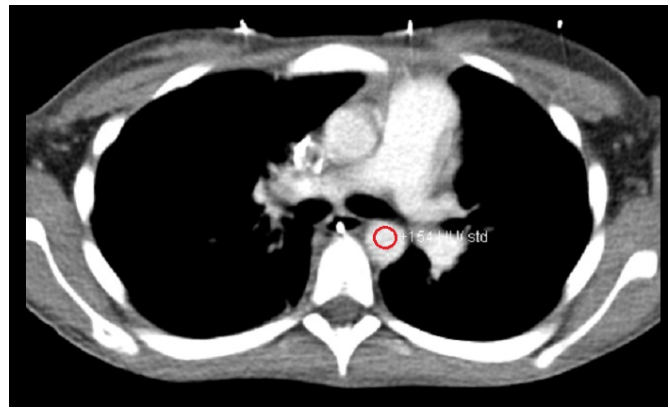


Fig. 2: Example of monitoring scan, with a region of interest in the descending aorta.

CT VB20A (2019) with a gantry rotation duration of 0.5 seconds. With children of age under 12 years, the pitch was 0.6, while for children of 12 years of older, the pitch was 1.4. When very young children were not able to hold their breath during scanning, a TurboFlash protocol was used, with a gantry rotation duration of 0.25 seconds and a pitch of 3.2. Voxel size was between  $0.33 \times 0.33 \times 1.00 \text{ mm}^3$  and  $0.69 \times 0.69 \times 1 \text{ mm}^3$ , depending on patient size. This resulted in a field of view diameter between 168 and 354 mm. Tube voltages ranged from 70kv to 100kv, or 150kv if the patient was scanned according to a dual energy protocol. All but three patients were scanned in cephalocaudal direction. The three other patients were scanned in opposite direction. The used contrast agent was Ultravist-300, which consists of an Iodine solution of 300 mg/ml. In two patients and three scans Omnipaque-300 was used instead, which is also an Iodine solution with the same concentration.

Fig. 3 shows the timings during the CECT scans. Two to ten seconds after applying contrast, a monitoring scan was acquired approximately every second. The image intensity in a region of interest placed beforehand, was measured in each scan. The region of interest was placed in the descending aorta, 1 cm above the diaphragm, as is shown in Fig. 2. When this intensity became higher than 100 HU, the acquisition of the arterial scan started after a specific delay time. In the old protocol this delay time was 7 seconds for age  $\leq 12$  years and 20 seconds for age  $> 12$  years. In the new protocol this delay was as small as possible. After a second delay, the portal-venous scan was acquired. In the old protocol, this second delay time very roughly depended on age (43 and 30 s for patients  $\leq 12$  years and  $> 12$  years respectively), while in the new protocol the delay time depends on the patient weight; the higher the patient weight, the longer the delay time. Not only the portal-venous scan delay depends on the patient body weight, also the flow rate and concentration varies with patient weight. The original protocols can be found in appendices A and B, while the new protocols can be found in appendices B and C.

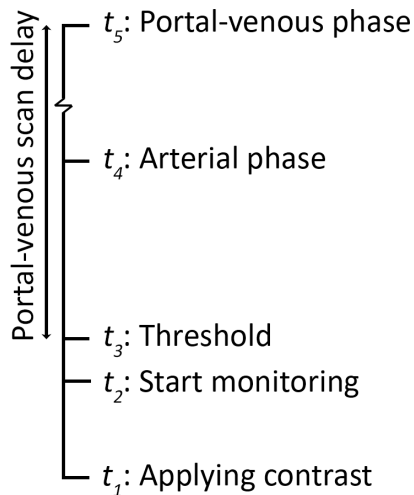


Fig. 3: Timings during the CECT scans. A short time (2-10 seconds) after applying contrast ( $t_1$ ), a repeating monitoring scan started ( $t_2$ ). After the image intensity in the aorta reached a threshold of 100 HU ( $t_3$ ), a timer started to acquire the arterial ( $t_4$ ) and portal-venous phase ( $t_5$ ) after a pre-determined time. The portal-venous scan delay is the delay between  $t_3$  and  $t_5$ .

### B. Analysis

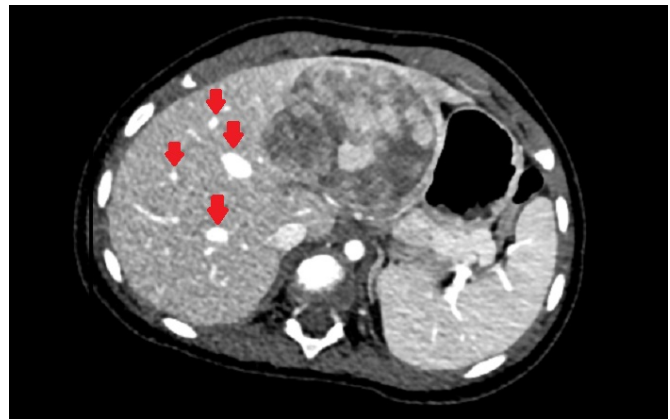
Parameters that were included in this research were sex, age, weight, length, contrast volume, flow rate, delay times, image quality and timing. From these variables, more variables could be determined, such as body surface area (BSA), contrast concentration and bolus length. BSA was calculated using the Mosteller formula [23], which is often used for calculating the BSA of children.

All scans were scored by an experienced radiologist, on a scale of 1 to 4 with the categories ‘bad’, ‘mediocre’, ‘sufficient’ and ‘good’. Furthermore, the radiologist tried to estimate whether the portal-venous scan was made at the correct time, too early or too late.

The main method of analysis made use of histograms, showing the distributions of scans over the previously mentioned parameters. The histograms were made using MATLAB R2019b. They consisted of stacked bars with different colors, where the colors represented groupings based on an additional parameter. For example, a histogram of the distribution of the patient age was made, where bars of different colors were stacked, with the different colors representing the scan quality. This way it was possible to not only investigate the distribution of the different parameters, but also to investigate how the parameters related to each other.

When there seemed to be a relationship between a parameter and the scan quality or the timing, further investigation was done by comparing this parameter to multiple different parameters.

Based on these results, recommendations were given on how to improve the protocol.



(a) This portal-venous scan of a 1 year old female was scored as having a good quality. The red arrows point to veins, which are clearly distinguishable.



(b) This portal-venous scan of a 12 year old male patient was scored as having a bad quality. The red arrows point to veins, which are almost not distinguishable.

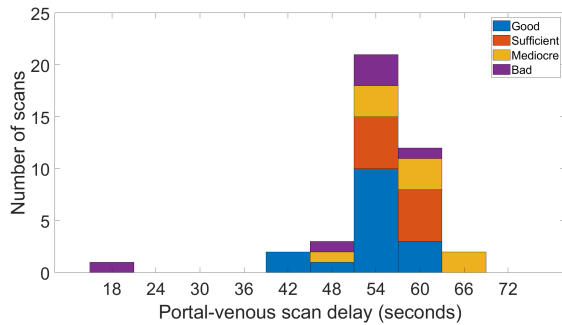
Fig. 4: Two examples of acquired scans, with red arrows pointing to liver veins.

### III. RESULTS

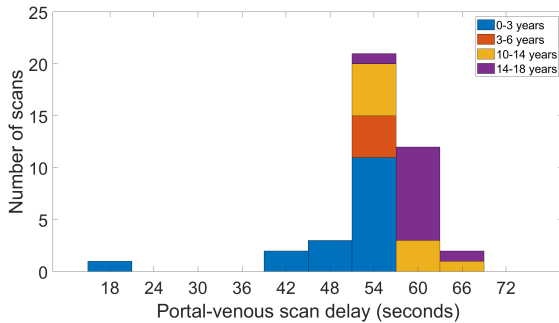
Fig. 4 shows an example of two acquired portal-venous scans. One of these scans (Fig. 4a) was scored as having a good quality, while the other scan (Fig. 4b) was scored as having a bad quality.

Fig. 5a shows the distribution of portal-venous scan delays, split into the scan quality categories as assessed by the radiologist. There is not a clear relationship visible here. Fig. 5b shows the distribution of portal-venous scan delays, split into different age categories. In this case there is a clear relationship visible, young patients have smaller scan delays than older patients. The used delay times often differed from the protocols, with an average difference in portal-venous delay time of  $7 \pm 6$  s.

Fig. 6a shows the relationship between patient age and scan quality of the portal-venous scan. It can be seen that most (7/8) of the scans that are scored bad by the radiologist, are made in patients with age  $< 6$  years, even though 38% of scans were made in patients with age  $> 6$  years. Fig. 6b, showing the relationship between patient age and scan timing, shows



(a) This figure breaks down the distribution of portal-venous scan delays into the four categories of quality of the portal-venous scan.



(b) This figure breaks down the distribution of portal-venous scan delays into four categories of patient ages. There is a clear relationship with patient age.

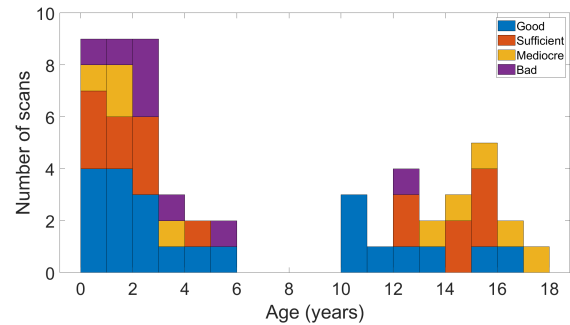
Fig. 5: This figure shows how the scans are distributed over the different portal-venous scan delays. For some scans the portal-venous scan delay is not known, so this histogram does not contain all scans.

TABLE I: This table shows the amount of scans in each timing and quality category. Both assessments (timing and quality) are concerning the portal-venous scan.

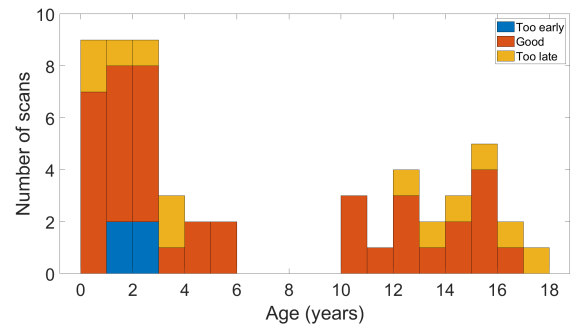
	Early	Good	Late	Total
Bad	1	2	5	8
Mediocre	2	0	7	9
Sufficient	1	15	0	16
Good	0	22	0	22
Total	4	39	12	55

that all four scans that were made too early according to the radiologist, are made in patients aged  $< 6$  years. Table I shows the relation between the scan quality and timing of the portal-venous scan. Five scans scored as being bad were acquired too late, while only one such scan was acquired too early. This one early bad scan was made in a 2 year old patient. Two scans scored as having a bad quality seemed to have a good timing according to the radiologist. These patients were aged 2 and 5.

Fig. 7a shows the distribution of the contrast concentration, split into categories of assessed scan quality. From this figure it follows that all of the scans scored as having a bad quality are made with a concentration lower than 1.4 ml/kg, even though 36% of scans have a concentration  $\geq 1.4$  ml/kg. The two scans scored as having bad quality, but a good timing, lie below this boundary of 1.4 ml/kg, these patients received contrast agent



(a) This figure breaks down the distribution of ages into the four categories of quality of the portal-venous scan. 7 out of 8 scans scored as being bad were made in patients aged 5 years old or younger.



(b) This figure breaks down the distribution of ages into the three categories of timing of the portal-venous scan. All early scans were made in patients aged 5 years old or younger.

Fig. 6: This figure shows how the scans are distributed over the different patient ages.

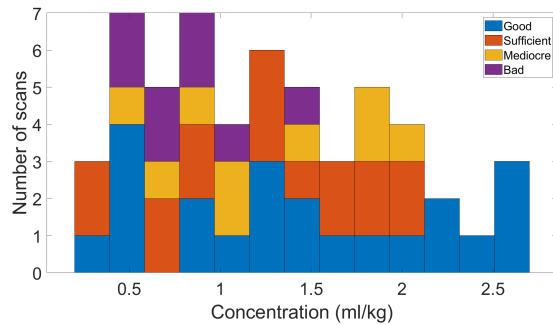
with a concentration of 0.87 and 1.01 ml/kg. Fig. 7b shows the relationship between the used contrast concentration and patient age. In 52 out of 55 cases, the patient received less contrast agent than prescribed in the protocol (on average  $1.5 \pm 0.7$  ml/kg below protocol), while in only 3 cases the patient received more (on average  $0.3 \pm 0.2$  ml/kg above protocol).

In Fig. 8a, where the relationship between flow rate and image quality is visualised, it can be seen that all of the scans scored as having bad quality are made with flow rates  $< 3$  ml/s. However, most scans scored as having good quality (19/22) are also made with flow rate  $< 3$  ml/s. Fig. 8b shows a clear relationship between flow rate and age, which is according to protocol.

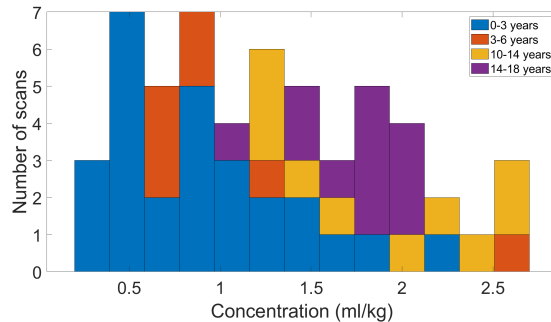
#### IV. DISCUSSION

The relationship between patient age and scan quality (Fig. 6a) shows that the most problematic scans are made in very young patients. The relationships between concentration and quality (Fig. 7a), and flow rate and quality (Fig. 8a) show that scans scored as having a bad quality mostly occur with scans with low concentration and flow rate.

The fact that a low concentration leads to low contrast between the liver veins and the liver parenchyma is not surprising. This has also been shown during previous research using part of the current dataset [22]. However, the fact that



(a) This figure breaks down the distribution of concentrations into the four categories of quality of the portal-venous scan. All scans scored as being bad are made in patients with a concentration less than 1.4 ml/kg.



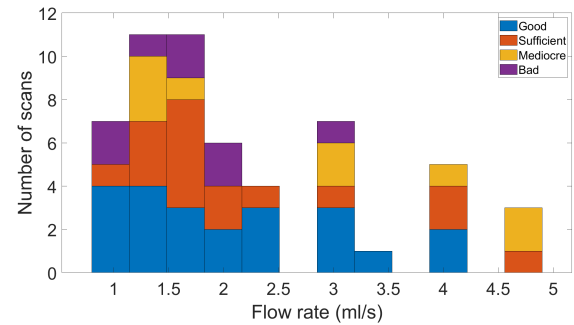
(b) This figure breaks down the distribution of concentrations into four categories of patient ages.

Fig. 7: This figure shows how the scans are distributed over the administered bolus concentrations.

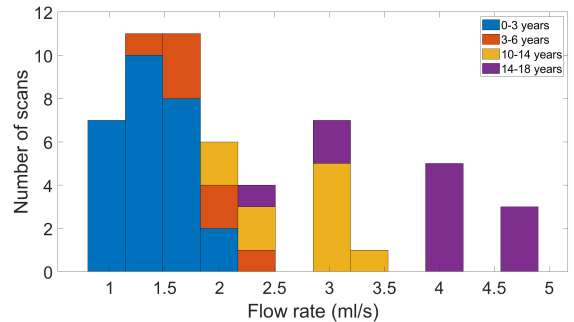
a significant number of scans scored as being bad have a concentration  $< 1.4$  ml/kg, can be used as a reason to increase the concentration in the current protocol to 2.5-3.0 ml/kg, depending on patient weight or age. These are similar values as in the original protocol. However, it is even more important to make sure the used contrast concentration agrees with the protocol, since 52 out of 55 scans are done with less contrast agent than prescribed in the protocol.

The relationship between a low flow rate and a low quality is less strong. Even though all scans scored as having a bad quality have a flow rate  $< 3$  ml/s, almost all good scans lie within the same region. Therefore the most important recommendation is the aforementioned recommendation on contrast concentration. If scans with high concentration still yield bad results, the flow rate can be increased, to see if this results in better scans. However, as is mentioned in the introduction, the maximum allowed flow rate is determined by the size of the access vein, so it cannot be increased for all patients.

As was shown in Table I, A significant number of bad and mediocre scored portal-venous scans were made too late (5 and 7), and just a few too early (1 and 2). From the sufficient scans only 1 was too early, and none were too late. Fig. 6b showed that all patients with age  $\geq 3$  which were either scanned on time or too late. All of these results point to the fact that scanning late occurs far more frequently than scanning early,



(a) This figure breaks down the distribution of flow rates into the four categories of quality of the portal-venous scan. All scans scored as being bad are made with flow rates less than 3 ml/s.



(b) This figure breaks down the distribution of concentrations into four categories of patient ages. There is a clear relationship between flow rate and patient age.

Fig. 8: This figure shows how the scans are distributed over the flow rate that was used during contrast administration.

especially with older children. This means that it might be beneficial to acquire the portal-venous scan earlier in general, but especially for the older children.

One should keep in mind that the results from this research are not tested statistically. The found relationships are not described mathematically, since that turned out to be difficult during this and previous research [22]. The given recommendation concerning concentration should not be applied blindly to all subsequent patients, but resulting scans must be continually monitored, to tweak all necessary scan parameters. Appendix D describes how new data can be included to create new histograms and do new data analysis. This user guide can be used to analyse any new addition to the dataset, and can be used in the long term to draw more statistically sound conclusions, to come to a better founded scan protocol.

During this research, most focus has been on the scans scored as being bad, and to a lesser extend on the scans scored as being good. However, a large portion of the scans were scored as being either mediocre or sufficient. This information has not been taken into account. If the given recommendation reduces the number of bad scans, the mediocre and sufficient categories become more relevant, because the scans that are now labeled as being mediocre scans, will then actually be the scans with lowest quality. Scans can then either be rated on a different scale, to differentiate between different types of mediocre scans, or research can focus on relationships between

parameters and the appearance of mediocre scans according to the current scale.

Unfortunately, no information was recorded on the cardiac output of the patients, such as heart rate and blood volume. However, such parameters might have a large influence on the optimal portal-venous scan delay. In patients with a fast heartbeat, the contrast bolus will reach the liver faster than in patients with a slow heartbeat. Therefore we recommend recording heart rate during future acquisitions, to be able to investigate its influence.

This research has focused on investigating if relatively small adjustments can be applied to the current protocol, to increase the scan quality of the portal-venous scan. However, a more fundamental change of the protocol is also possible, which is using bolus tracking for the portal-venous scan. Currently, bolus tracking is used for the arterial phase, by monitoring the image intensity in the aorta. Something similar can be done for the portal-venous phase, by for example setting one or more regions of interest in the liver parenchyma. The image intensity of the liver parenchyma correlates with the image intensity in the liver veins, and can therefore potentially be used as surrogate to determine the ideal time to scan the portal-venous phase. This type of bolus tracking has been investigated previously, with various results [6, 20, 21, 24]. Using bolus tracking can lead to a better estimation of the optimal portal-venous scan delay, resulting in higher quality images.

## V. CONCLUSION

Based on the data as presented in this research, we recommend to increase the administered contrast concentration to 2.5 ml/kg or higher, possibly based on patient age or weight. Furthermore, it is of utmost importance that the amount of administered contrast is according to protocol. The data of each future scan can be added to the current dataset to learn more about relationships between parameters, which could lead to further changes in the protocol. We also recommend to record the heart rate of the patients, since this might have a large influence on the optimal portal-venous scan delay. Two relationships that stand out in this research, but on which we do not have enough information to draw definitive conclusions, are the fact that there are no bad scans with a flow rate  $> 3$  ml/s and the fact that the older children (aged 10 years or older) are never scanned too early, only on time or too late. If there are still no bad scans with high flow rates after more data collection, it might be beneficial to increase the flow rate in the protocol, as long as this is possible, considering limiting factors such as cannula size. Similarly, if more data supports the observation that older children are only scanned on time or too late, the protocol could be changed to reduce the portal-venous scan delay for older children.

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APPENDIX A  
OLD PROTOCOL: PATIENT OF 12 YEARS OLD AND YOUNGER

*A. Instructions*

- 1) Place patient in supine position, 'feet first', with the arms next to the head.
- 2) Plan the pre-monitoring and monitoring scan at the start of the volume.
- 3) Scan 1, arterial. Make a scan from 1 cm above the diaphragm until the lower part of the liver. Make sure the whole tumor is covered!
- 4) Scan 2, portal-venous. Make a scan from 1 cm above the diaphragm until the lower part of the symphysis.
- 5) Place the ROI in the aorta
- 6) Inject the contrast agent, and start the scan simultaneously. When the threshold has reached a value of 100 HU, there is a 7 second delay for the breath-hold instructions. The second scan is made 43 seconds after the first scan.

*B. Contrast*

Never administer more than 150cc of contrast agent.

TABLE II: Contrast parameters

Age	Cannula size		Flow	Volume
< 1 years	24	Contrast	1.5 ml/s	2.5 ml/kg
		NaCl	1.5 ml/s	6 ml
1-5 years	22	Contrast	2 ml/s	2.5 ml/kg
		NaCl	2 ml/s	8 ml
5-10 years	20	Contrast	2.5 ml/s	3 ml/kg
		NaCl	2.5 ml/s	10 ml
> 10 years	20	Contrast	3 ml/s	3 ml/kg
		NaCl	3 ml/s	12 ml

*C. Acquisition parameters*

TABLE III: Acquisition parameters TurboFlash child protocol  
Surviview cranio-caudal: 100 kV, 20 mAs

	Arterial	Portal
Scan direction	Cranio-caudal	Cranio-caudal
Care kV	On	One
Ref. kV	100	100
Caredose 4D mAs	On	On
Quality ref. mAs	200	200
Admire level	3	3
Pitch	3.2	3.2
Gantry rotation time	0.25	0.25
Kernel	Br40	Br40
WW/WL	Abdomen (400/40)	Abdomen (400/40)
Post-threshold delay	7 sec.	50 sec.

TABLE IV: Acquisition parameters child protocol  
Surviview cranio-caudal: 100 kV, 20 mAs

	Arterial	Portal
Scan direction	Cranio-caudal	Cranio-caudal
Care kV	On	One
Ref. kV	100	100
Caredose 4D mAs	On	On
Quality ref. mAs	200	200
Admire level	3	3
Pitch	1.4	1.4
Gantry rotation time	0.5	0.5
Kernel	Br40	Br40
WW/WL	Abdomen (400/40)	Abdomen (400/40)
Post-threshold delay	7 sec.	50 sec.



## APPENDIX B

OLD AND NEW PROTOCOL: PATIENT OLDER THAN 12 YEARS OLD (OLD) OR OLDER THAN 14 YEARS OLD OR OVER 50 KG (NEW)

A. *Instructions*

- 1) Place patient in supine position, 'feet first', with the arms next to the head.
- 2) Choose the dual energy protocol.
- 3) Plan the pre-monitoring and monitoring scan at the start of the volume.
- 4) Scan 1, arterial. Make a plan of the liver. (At the thorax/liver 2F liver, diaphragm to the top of the longs, and (pre-)monitoring on the diaphragm).
- 5) Scan 2, portal-venous. Plan 1 cm above the diaphragm until the ischial bone.
- 6) Place the ROI in the aorta
- 7) Take a threshold of 100 and a post threshold delay of 20 sec. for scan 1 and 50 sec. for scan 2.
- 8) Scanprotocol and contrastpump are coupled.

B. *Contrast*

The flow rate is always 5 ml/s. The volume of NaCl is always 50 ml, and the contrast concentration is 1.67 ml/kg, except when the patient weight is smaller than 60 kg, in that case the amount of contrast is always 100 ml, and when the patient weight is larger than 115 kg, in that case the amount of contrast is always 192 ml.

C. *Acquisition parameters*

TABLE V: Acquisition parameters adult protocol  
Surview cranio-caudal: 120 kV, 20 mAs

	<b>Arterial</b>	<b>Portal</b>
Scan direction	Cranio-caudal (with thorax/liver it is caudocranial)	Cranio-caudal
Care kV	On	One
Ref. kV	100kV/Sn150	100kV/Sn150
Caredose 4D mAs	On	On
Quality ref. mAs	140/70	140/70
Admire level	3	3
Pitch	0.6	0.6
Gantry rotation time	0.5	0.5
Kernel	Br40	Br40
WW/WL	Abdomen (400/40)	Abdomen (400/40)
Post-threshold delay	20 sec.	50 sec.

## APPENDIX C

## NEW PROTOCOL: PATIENT OF 14 YEARS OLD AND YOUNGER AND LESS THAN 50 KG

## A. Instructions

- 1) Place patient in supine position, 'feet first', with the arms next to the head.
- 2) Plan the pre-monitoring and monitoring scan at the start of the volume.
- 3) Scan 1, arterial. Make a scan from 1 cm above the diaphragm until the lower part of the liver. Make sure the whole tumor is covered!
- 4) Scan 2, portal-venous. Make a scan from 1 cm above the diaphragm until the lower part of the symphysis.
- 5) Place the ROI in the aorta
- 6) Inject the contrast agent, and start the scan simultaneously. When the threshold has reached a value of 100 HU, there is a minimum delay, so give the breath-hold instructions before it goes through the tracker. The second scan depends on the weight, according to the table below. The contrast concentration is always 2 ml/kg. The NaCl concentration is always 1 ml/kg, but never more than 40 ml/kg.

## B. Delay and flow rate

TABLE VI: Contrast parameters

Weight in kg	Flow in ml/sec	Delay portal-venous scan in sec.
2	1	18
4	1	30
6	1	37
8	1	41
10	1.5	45
12	1.5	48
14	1.5	51
16	1.5	53
18	1.5	55
20	2	57
22	2	58
24	2	60
26	2	62
28	2	64
30	2.5	66
32	2.5	68
34	2.5	69
36	2.5	70
38	2.5	71
40	3	72
42	3	73
44	3	74
46	3	75
48	3	75
50	4	75

## C. Acquisition parameters

TABLE VII: Acquisition parameters TurboFlash child protocol  
Surview cranio-caudal: 100 kV, 20 mAs

	Arterial	Portal
Scan direction	Cranio-caudal	Cranio-caudal
Care kV	On	One
Ref. kV	100	100
Caredose 4D mAs	On	On
Quality ref. mAs	200	200
Admire level	3	3
Pitch	3.2	3.2
Gantry rotation time	0.25	0.25
Kernel	Br40	Br40
WW/WL	Abdomen (400/40)	Abdomen (400/40)
Post-threshold delay	Minimum	Delay table - (delay arterial + scan time arterial)

TABLE VIII: Acquisition parameters child protocol  
 Surview cranio-caudal: 100 kV, 20 mAs

	<b>Arterial</b>	<b>Portal</b>
Scan direction	Cranio-caudal	Cranio-caudal
Care kV	On	One
Ref. kV	100	100
Caredose 4D mAs	On	On
Quality ref. mAs	200	200
Admire level	3	3
Pitch	1.4	1.4
Gantry rotation time	0.5	0.5
Kernel	Br40	Br40
WW/WL	Abdomen (400/40)	Abdomen (400/40)
Post-threshold delay	7 sec.	Delay table - (delay arterial + scan time arterial)

APPENDIX D  
USER GUIDE FOR INCLUDING FUTURE DATA

This user guide will explain how new data can be added to the dataset (appendix D-A and D-B) and how this data can be used to do the analysis again (appendix D-C). To be able to use this guide, one must have access to the original data and the analysis files. Note that detailed explanations of each function are also included in the functions themselves.

*A. Creating data table*

This section is relevant in case the MATLAB table with all the data is lost, or if you want to recreate it for another reason. If you only want to add a single new scan to the table, you can skip to appendix D-B.

To create a new data table, you must first have an excel document in the correct format, as well as a txt file which points to the folders containing the DICOM files, see the explanation in appendix D-B. To create a new table, the MATLAB function ‘createDataTable’ must be used. An example of its usage can be found in ‘dataAdditions.m’. If this new table contains more data than originally, make sure you also read appendix D-B, since the ‘addSingleScan’ is called inside of the ‘createDataTable’ function. If you would want to add more variables than there are currently, you have to add the name of the variable in ‘data\_titles’, add the class of the variable in ‘data\_variable\_types’, and update the ‘addSingleScan’ function to get the information from either the excel file or the DICOM tags.

If any errors occur in the process of creating a new data table, the most probable causes are either in the ‘extractInfoFromDataFolderTxt’ function or the ‘addSingleScan’ function, which are both explained in appendix D-B.

*B. Adding a new scan*

To add a new scan to the MATLAB table, the following steps have to be performed. NOTE: if you want to change the pseudo nr of a scan already in the table, the table must be created again from scratch using appendix D-A. Changing any other value can simply be done by changing the relevant value either the excel table or the filepath text file (see below) and then calling the ‘addSingleScan’ function with the relevant pseudo nr.

1. There is an excel table with information about all of the scans. The file containing the current data is named ‘CT scans data.xlsx’. Note that it is in Dutch. Data from a new patient can be added by simply adding a new line at the bottom. Make sure you add as much information as possible here. Usually missing information will cause no problem, but in some cases this will cause errors, namely when either ‘pseudo nr’, ‘scandatum’ or ‘contrastmiddel’ is omitted.

Extra notes: Column names may never be changed. However, extra columns can be added without any problems. The only thing to keep in mind is that the column ‘pseudo nr’ must always be the second column. Adding columns in the excel file will not automatically add them to the MATLAB table, to do that, the ‘addSingleScan’ and ‘createDataTable’ functions must be changed to allow for this new column.

2. There is a text file (currently called ‘Filepaths.txt’), which contains the file paths of all of the DICOM files. The first line (Filepaths) may never be removed. To add a new scan, simply add it in the same format as the previous scans. Note that it is possible to omit the monitoring scan, if it was not saved. However, the pseudo nr, arterial scan and portal-venous scan must always be provided. Note that all the folders with DICOM scans must be in the same folder (in the example this is ‘H:\E\_ResearchData’, which can be seen in the example file ‘dataAdditions.m’). The folders which are written down in the text file must be relative to this main folder. The folders may only contain DICOM files, and no other files.

3. Now the only thing left to do is calling the function ‘addSingleScan’. An example of this is shown in ‘dataAdditions.m’. It can be called such that the current MATLAB table is updated, or such that the table containing the extra line is created in a new file. Overwriting the original table is irreversible. However, you can always create a new table using the guide in appendix D-A.

NOTE: Sometimes the ROI in the aorta is not placed correctly. This can only be seen when viewing the monitoring scan in a DICOM viewer. If you notice that this is the case, you should include an exception for this in the ‘addSingleScan’ file. This can be done just above where the arterial scan is read, currently around line 100. Searching for ‘ROI’

in the function will bring you to the correct place.

4. Ideally there are no errors, and the new data is added to the table, in that case this section can be skipped. However, there are several locations where errors could occur, and here I will explain how to handle some of these errors.

‘Error: Keyword ... not recognized’. You probably made an error in the txt file. Make sure you use the correct format.

‘Error: PseudoNr appears twice!’. Either in the excel table or in the MATLAB table, a pseudo nr appears twice.

‘Error: This is no ... scan’. First check if the filepath in the text file indeed points to the correct folder with scan(s). If this is the case, check the DICOM tags of one of the scans/slices, using either a DICOM viewer or MATLAB. Check the tag ‘SeriesDescription’, to see if the scan type is indeed correct. If it is correct, then go to the location in the code where the error was thrown. Probably the series description uses another convention than when the code was written. Add a check such that it accepts this convention as well.

‘Error: Reference to non-existent field ...’. Probably a certain DICOM tag is not found. This can be solved by creating an exception, such that when scans with this pseudo nr are added to the table, instead of trying to find this dicom tag, it is added ‘manually’. If you know the correct value of the tag, you can add it, otherwise you can set it to missing. This must be implemented in the ‘addSingleScan’ function. After you implemented it, you can run the function again, and if all is well, the error is gone. It should look something like this:

```
if PseudoNr == "..."  
    value = missing;  
else  
    value = info ....;  
end
```

‘Error: Contrasttype in DICOM file does not correspond with contrasttype in excel table’. This can be solved by introducing an exception, as is shown with the previous error. The best location to introduce this exception is where the arterial scan is read, currently around line 150 (but this will of course change if the code is changed).

Any other error: Either the error explains itself, so it is not mentioned here, or the error can have any number of causes, so it cannot fully be explained

here. In the latter case you can try to find the solution yourself, or you can ask me to look for it, since I know the structure of the code very well.

### C. Analysis

The file ‘analysis.m’ can be used to do any analysis, using the MATLAB table. It can be used to create histograms, as well as to do other types of data analysis. When this file is run, almost all data mentioned in this paper can be reproduced. When this file is run after more data has been added, the influence of this new data can be seen in the results. The explanation on how to use this file is written using comments in the file itself.

APPENDIX E  
LAYMAN'S SUMMARY

Lever tumoren bij kinderen worden vaak onderzocht met behulp van CT scans. Een belangrijk doel van deze scans is om de aderen in de lever goed in beeld te brengen. Bij deze CT scans krijgen de kinderen een contrastmiddel toegediend in hun bloed. Nadat het contrast is toegediend, wordt er gewacht totdat deze vloeistof de lever bereikt heeft, waarna de CT scan gestart kan worden. Dit contrastmiddel zorgt ervoor dat het contrast tussen de aderen en het leverweefsel groter wordt, zodat de aderen duidelijk te onderscheiden zijn.

De lever wordt doorbloed op verschillende manieren. Eerst komt bloed binnen via de leverslagader, die bloed vanuit het hart brengt, en later via de leverpoortader, die bloed van de darmen, maag, milt en alvleesklier naar de lever vervoert (zie figuur 9 op de volgende pagina voor meer informatie over de bloedvoorziening van de lever). Om deze twee verschillende vormen van bloedtoevoer in beeld te brengen worden er twee scans gemaakt. De eerste scan gaat meestal wel goed, maar de tweede scan is bij kinderen lastig te timen. Hierdoor is de kwaliteit van de tweede scan soms niet voldoende (zie figuur 10a voor een goede en figuur 10b voor een slechte scan).

Ik heb gekeken naar een verzameling van 55 scans, gemaakt van 40 kinderen, om te kijken of er relaties te vinden zijn tussen verschillende parameters (zoals de hoeveelheid contrast, de snelheid van het toedienen van het contrast, maar bijvoorbeeld ook het gewicht, de lengte en de leeftijd van de patiënten, de scankwaliteit en timing van de scans). Een radioloog heeft alle scans beoordeeld op scankwaliteit en timing.

Tijdens het onderzoeken van de data vielen er een aantal dingen op. Ten eerste blijkt dat bijna alle scans met een lage kwaliteit scans zijn van kinderen van 6 jaar of jonger, dus daar ligt het grootste probleem. We zien ook dat alle scans die te vroeg zijn gemaakt zich in deze categorie bevinden. Verder valt het op dat alle scans met een lage kwaliteit gemaakt waren met een lage concentratie contrastvloeistof. Dit zou veroorzaakt kunnen worden door het feit dat patiënten bijna altijd minder contrastvloeistof toegediend krijgen dan in het protocol staat. Om deze reden raad ik aan om bij toekomstige scans de concentratie contrastvloeistof wat te verhogen, en om in ieder geval het protocol op te volgen. Daarnaast lijkt het erop dat de slechte scans vooral voorkomen als de toedieningssnelheid van het contrast laag is, dus eventueel zou die iets verhoogd kunnen worden. Dat is echter niet voor alle patiënten mogelijk, want jonge patiënten met kleine aderen kunnen geen hele hoge toedieningssnelheid aan. In de toekomst zouden we verder graag meer willen weten over de hartslag van de patiënten tijdens de scans, want deze kan een belangrijke rol spelen bij de snelheid waarmee het bloed bij de lever aankomt.

De hiervoor benoemde aanbevelingen kunnen worden toegepast in het scanprotocol, maar er moet wel voorzichtig mee om worden gegaan. Als er nieuwe scans zijn gemaakt, moeten deze worden toegevoegd aan de huidige database, zodat er onderzoek gedaan kan worden naar de invloed van de veranderingen. Eventuele problemen kunnen op deze manier tijdig worden opgevangen.

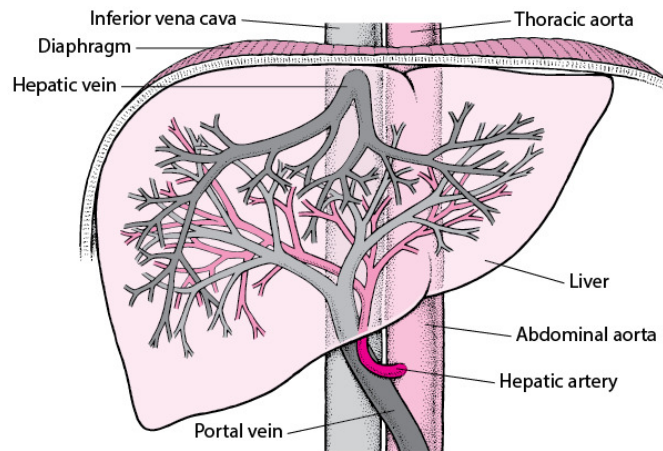
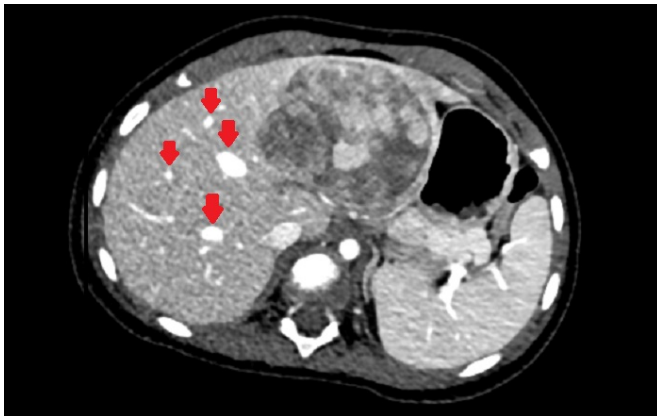


Fig. 9: De bloedsomvoer in de lever.



(a) Een scan die beoordeeld is als een goed scan. De rode pijlen wijzen naar aderen, die goed zichtbaar zijn.



(b) Een scan die beoordeeld is als een slechte scan. De rode pijlen wijzen naar aderen, die haast niet te onderscheiden zijn.

Fig. 10: Een voorbeeld van CT scans.