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CT volumetry with three-dimensional modelling in the preoperative management of patients with alveolar echinococcosis of the liver

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Abstract. Alveolar echinococcosis of the liver is a chronic parasitic disease with an infiltrative growth pattern, leading to progressive destruction of the hepatic parenchyma and involvement of the vascular-biliary structures. The prolonged course of the disease is often accompanied by a compensatory increase in the total volume of the liver, which is important when assessing resectability and determining surgical tactics. One of the key parameters of preoperative planning is the Future liver remnant, an indicator that characterises the morphological reserve and allows predicting the likelihood of postoperative liver failure. The aim of the study was to evaluate the diagnostic value of computed tomography volumetry and virtual resection in planning surgical treatment for patients with alveolar echinococcosis of the liver. The study included 59 patients with a confirmed diagnosis who were examined at medical centres in Bishkek in 2023-2025. All patients underwent multispiral computed tomography with intravenous contrast, and post-processing was performed using the LiverAnalysis+ software package. The total liver volume, the volume of affected tissue, the estimated resection volume, and the Future liver remnant were assessed. The average total liver volume in patients without previous surgery was 2,008 cm^3, reflecting compensatory hypertrophy in the long-term course of the disease. In patients after surgery, this indicator was lower – 1,635 cm^3. The average Future liver remnant was 1,162 cm^3 (57.9%) in patients without surgery and 774 cm^3 (49.7%) in patients after resection. In one-third of the operated patients, the Future liver remnant was below the critical level (<30–40%), indicating an increased risk of developing liver failure. The results confirmed that computed tomography volumetry with virtual resection is an essential tool for assessing surgical risks and should be included in the standard preoperative planning for the treatment of patients with alveolar echinococcosis of the liver

Keywords: alveolar echinococcosis of the liver; CT volumetry; Future liver remnant; preoperative planning; postoperative liver failure

Introduction

Liver volumetry – a method for quantitatively assessing the total liver volume (TLV), its segments, pathological inclusions, and the future liver remnant (FLR) based on medical imaging data [1]. The most accurate and widely used preoperative tool is computed tomography (CT) with volumetry, based on automatic or manual segmentation of the liver and lesions using CT data with bolus contrast [2] Magnetic resonance imaging (MRI) with volumetry is similar to CT volumetry, but is used less frequently due to its higher cost and limited availability, and is mainly used in patients with impaired renal function when iodine-containing contrast for CT is contraindicated. Volumetric ultrasound (ultrasound examination with volumetry and three-dimensional modelling, 3D-US volumetry) is a method of quantitative assessment of organ volume using three-dimensional ultrasound imaging, mainly used to assess foetal liver volume [3]. This method can be useful

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when CT or MRI are unavailable or undesirable [4], as well as during surgery for surgical navigation [5]. However, ultrasound volumetry still has low accuracy and is used only for a rough estimate of liver volume, while transient elastography serves as an additional tool for stratifying the risk of post-hepatectomy liver failure (PHLF) [6].

An objective assessment of the functional capacity of the future liver remnant (FLR) is performed using methods such as hepatobiliary scintigraphy with 99Tc-meobrofenin [7], functional MRI with Gd-EOB-DTPA contrast (Gadolinium-Ethoxybenzyl-Diethylenetriamine Pentaacetic Acid) [8]. These methods help to determine the viability of the remaining tissue, especially in cases of diffuse liver parenchymal damage, which is impossible with standard CT volumetry [9].

Alveolar echinococcosis of the liver (AEL) is an infiltrative parasitic lesion that resembles malignant tumours in its behaviour and often requires extensive resection and complex preoperative planning [10,11]Due to the frequent involvement of large vessels and extensive damage to the liver parenchyma, accurate preoperative planning, including volumetry and three-dimensional modelling, is particularly important in order to assess resectability and predict the functional adequacy of the remaining part of the organ [12].

Computed tomography with intravenous bolus contrast is one of the main methods for diagnosing parasitic liver lesions [13]. However, specialised software is required for detailed image analysis, assessment of the extent of the lesion, and calculation of the FLR prior to surgical intervention [14]. One such tool is LiverAnalysis+, a software package designed for automatic segmentation, volumetry, and analysis of liver function parameters. The aim of the study was to evaluate the diagnostic and planning capabilities of CT volumetry of the liver using the LiverAnalysis+ software package in patients with alveolar echinococcosis of the liver.

Materials and Methods

Study design: retrospective, multicentre. The study was based on a retrospective analysis of bolus contrast CT scans in patients with alveolar echinococcosis of the liver between 2023 and 2025. Data were collected at three diagnostic centres in Bishkek: the "System" Medical Centre, the SRM Medical Centre, and the National Centre of Cardiology and Therapy (Department of Diagnostic Imaging). The study included 59 patients with a confirmed diagnosis of AEL, of whom 30 were men (50.8%) and 29 were women (49.2%); age ranged from 13 to 69 years (mean age 37.9 years). Inclusion criteria were:

- Clinically and morphologically confirmed diagnosis of alveolar echinococcosis of the liver;
- Availability of CT scan of the abdominal organs with bolus contrast;
- CT volumetry using LiverAnalysis+.

Exclusion criteria were:

- Patients with unsatisfactory contrast enhancement;
- Cases in which the diagnosis of parasitic liver damage was not confirmed by other methods of radiological diagnosis or histological examination;
- Patients with combined liver damage (parasitic and neoplastic processes).

The CT protocol included 0.5-1 mm slices, 3 phases of contrast enhancement using the standard technique. Post-processing of DICOM data in LiverAnalysis+.

The main tasks of CT volumetry of the liver: determination of total liver volume (TLV) – calculation of the total volume of the organ, including healthy and pathologically altered tissue; assessment of the volume of affected tissues – determination of the part of the liver involved in the pathological process; segmentation of the liver – the process of calculating the volume of each segment of the liver separately, based on the location of the hepatic veins and branches of the portal vein; performing virtual liver resection (VR resection) to simulate possible surgical options; calculation of residual Future Liver Remnant (FLR) – prediction of the volume of liver that will remain after resection; prediction of the development of postoperative liver failure – the minimum acceptable FLR that ensures sufficient liver function after surgery; monitoring of changes – assessment of changes in liver volume in diseases, after surgical interventions, during multi-stage surgical interventions such as ALPPS (Associating Liver Partition and Portal vein Ligation for Staged hepatectomy, two-stage liver resection with portal vein ligation and parenchymal division).

The steps for calculating liver volume in the LiverAnalysis+ programme included several sequential steps. Import of DICOM CT data with bolus contrast. Automatic liver segmentation – the programme's algorithms determine the boundaries of the organ, excluding neighbouring structures (gallbladder, stomach, etc.). Segmentation according to the Couinaud classification – automatic or semi-automatic division of the liver into segments, highlighting vascular structures, and construction of a 3D model. Lesion assessment – the operator manually or semi-automatically selects the lesions, and the programme calculates their total volume. Virtual liver resection – anatomical or atypical variants are possible with resection line modelling. FLR calculation in the LiverAnalysis+ software package was performed automatically using two mathematical models reflecting different approaches to assessing functionally preserved parenchyma. Formula 1 – taking into account the volume of tumour lesions (1):

$$FLR\ (\%) = \left(\frac{V_{FLR}}{V_{Total} - V_{Tumor}}\right) \times 100. \qquad (1)$$

where V_{frl} – the volume of the remaining part of the liver after resection, V_{Total} – total liver volume, V_{Tumor} – volume of the tumour to be removed.

This formula takes into account the fact that the affected areas of the liver do not participate in metabolic processes, and thus provides an FLR value that is closer to a functional assessment. However, the method remains approximate, since the volume of pathological tissue does not always linearly reflect the degree of functional loss. Formula 2 – classic volumetric (2):

$$FLR\% = \frac{V_{FRL}}{V_{totalL}} 100. \quad (2)$$

where V_{FRL} – volume of the remaining part of the liver after resection, V_{Total} – total liver volume.

This method is the standard in volumetry and is used in most clinical studies and preoperative planning protocols [15]. Although it does not take non-functioning tissue into account, it ensures the stability of calculations and the comparability of data between different patients and centers. These calculations allow for a quantitative assessment of the residual liver volume and prediction of the risk of postoperative insufficiency [16]. The difference between the first formula is that it takes into account the volume of the tumour that does not participate in the functional work of the liver, so this form is close to the functional method of measuring FLR, but it is not sufficiently accurate. In this study, to ensure sample homogeneity and data comparability, the FLR was calculated using the classic Formula (2), based on the ratio of the residual liver volume to the total organ volume. Clinical significance of FRL:

- FRL ≥ 30% – safe volume in healthy patients;
- FRL ≥ 40-50% – necessary FLR volume in chronic diseases (cirrhosis, steatosis, condition after chemotherapy, etc.).

Statistical data processing. Data analysis was performed in IBM SPSS Statistics 23.0. Descriptive analysis was performed to determine the mean, standard deviation, median, minimum and maximum values. The normality of the distribution was checked using the Shapiro-Wilk test. Data visualisation was performed using histograms and boxplots reflecting the median, interquartile range, and outliers. The level of statistical significance was $p < 0.05$.

Results

Post-processing of CT data from 59 patients was performed using the LiverAnalysis+ software package (Fig. 1).

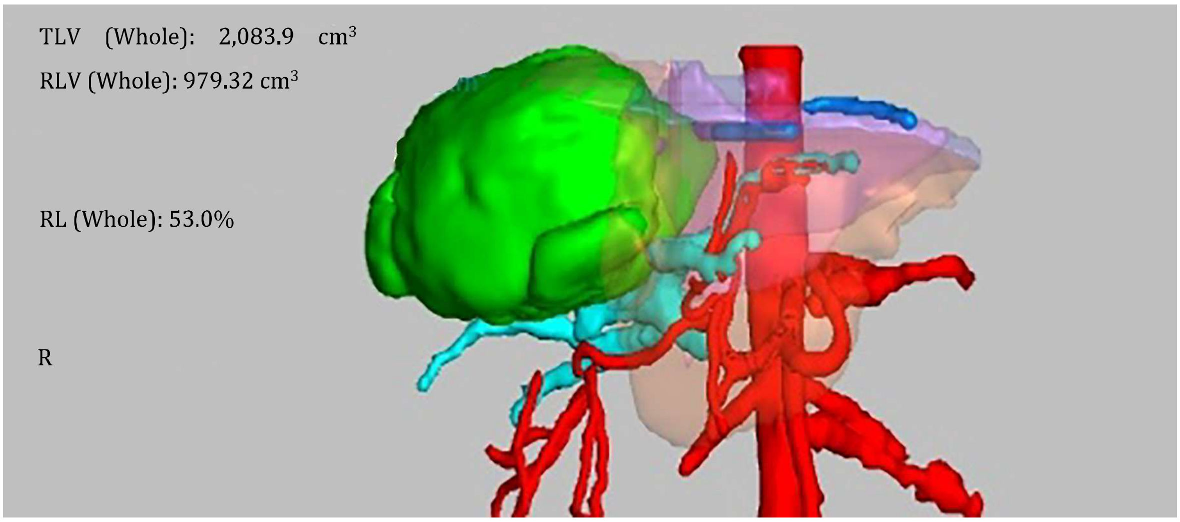

Figure 1. 3D reconstruction of the liver with a large parasitic node (green formation) during processing by the *LiverAnalysis+* programme

Source: created by the author

Most patients (78.0%) had a single lesion (Table 1). Sixteen point nine per cent of patients had two lesions, and only 5.1% had three or more. The average number of lesions was 1.32 (± 0.75).

Table 1. Distribution of patients by number of liver lesions

Number of lesions	Frequency (n)	Percentage (%)	Cumulative percentage (%)
1	46	78.0	78.0
2	10	16.9	94.9
3	1	1.7	96.6
4	1	1.7	98.3
5 or more	1	1.7	100.0

Source: created by the author

In the sample studied, 79.7% of patients (n = 47) had not undergone surgical treatment at the time of CT volumetry, while 20.3% (n = 12) had undergone various types of surgical interventions. Among the surgical procedures, atypical resections (8.5%) and left-sided hemihepatectomy (5.1%) were the most common, while segmentectomy, sectorectomy, and right-sided hemihepatectomy were less common.

For further analysis, patients were divided into two groups:

- Group 1 – patients who did not undergo surgery (n = 47);
- Group 2 – patients who underwent various types of liver resection (n = 12).

This approach allowed for a more detailed study of the effect of lesion volume, degree of vascular invasion, and volumetry parameters on the effectiveness of preoperative planning based on CT volumetry.

In patients without surgery, the average liver volume is greater than in patients after surgery, by approximately 300-400 cm^3. The spread of values in the group without surgery was also significantly more pronounced (wide range), with a predominance of increased volumes of liver parenchyma. This phenomenon is consistent with the literature, according to which patients with alveolar echinococcosis of the liver often experience a compensatory increase in total liver volume due to the prolonged chronic course of the disease [17]. The central tendency and dispersion indicators were calculated for each group (Table 2). The table shows that in patients without surgery, the average liver volume is 2,008 cm^3, while in patients after surgery, it is about 1,635 cm^3. The difference in average volumes is approximately 15-20% in favour of the group without surgery.

The histograms (Fig. 2) show the distribution of liver volume for each group. It can be noted that the distribution shapes are close to normal (bell-shaped). The box plot (Fig. 2) clearly compares the medians and the spread of liver volume in the two groups. In patients who have not undergone surgery, the median is higher, the interquartile range is wider, and higher values are observed.

Table 2. Descriptive statistics of liver volume in patients without surgery and after surgical intervention

Indicator	Without surgery (n = 47)	After surgery (n = 12)
Mean volume, cm^3	2,008	1,635
Median, cm^3	1,874	1,578
Standard deviation, cm^3	728	1,014
Range, cm^3	868-4,400	829-2,416

Source: created by the author

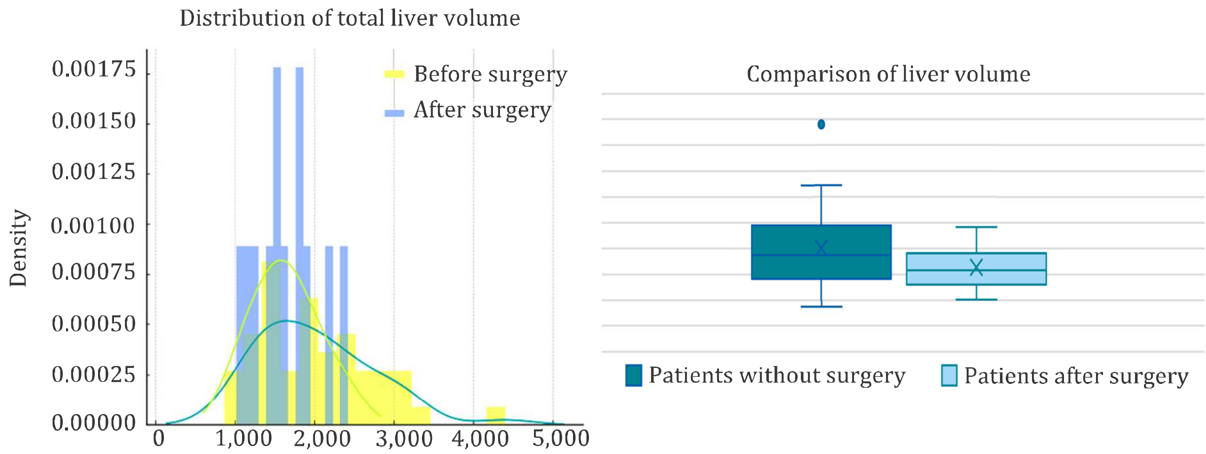

Figure 2. Distribution of liver volume in patients

Source: created by the author

In patients without surgical interventions, the mean volume of parasitic lesions was 658 cm^3 and the median was 411 cm^3, whereas in patients who had undergone surgery these values were 243 cm^3 and 85 cm^3, respectively (Fig. 3). The maximum lesion volume in the first group reached 2,580 cm^3, compared with 1,035 cm^3 in the second group, reflecting a significantly more extensive disease process in non-operated patients.

In relative terms, the mean volume of liver involvement in patients without surgery was 28.4% of the total liver volume (median 24.6%, range 0.1–80.5%), whereas after surgical interventions it was 12.5% (median 5.7%, range 3.1–42.9%). As shown by the data, in non-operated patients the extent of involvement, both in absolute and relative terms, was approximately 2.5–5 times greater than in patients after liver resections.

All patients underwent virtual liver resection (VR resection) to model possible surgical treatment options. The selection of the optimal surgical approach was carried out in collaboration with experienced surgeons with many years of expertise in the surgical management of alveolar echinococcosis of the liver (Fig. 4).

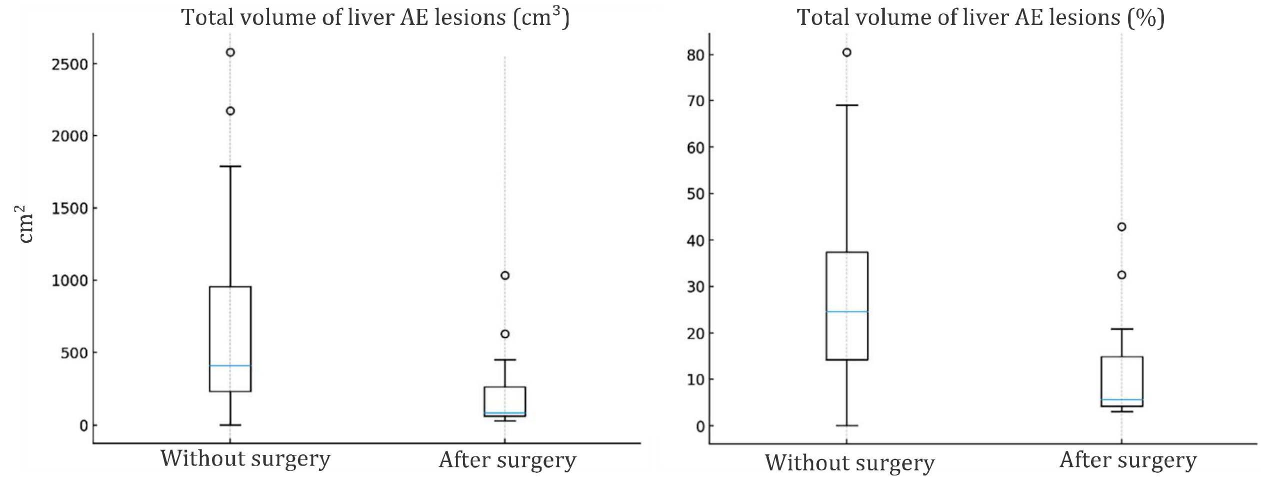

Figure 3. Volume of liver alveolar echinococcosis lesions
Source: created by the author

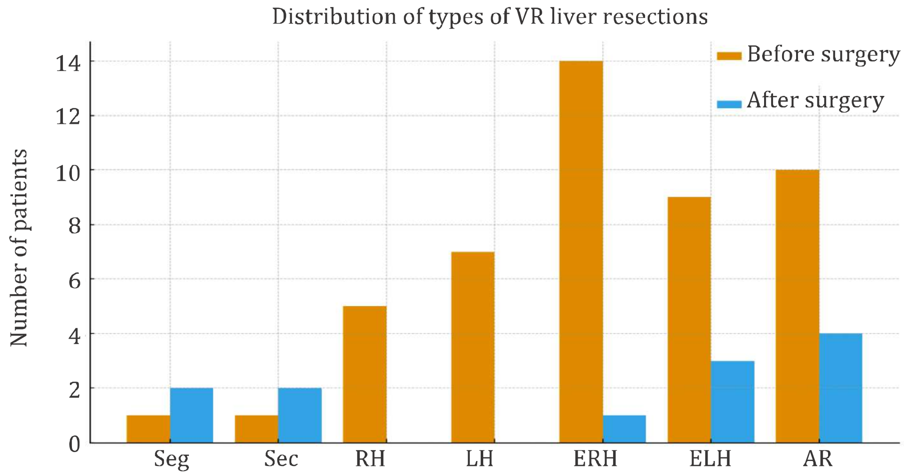

Figure 4. Types of virtual liver resections
Note: Seg – Segmentectomy; Sec – Sectorectomy; RH – Right hemihepatectomy; LH – Left hemihepatectomy; ERH – Extended right hemihepatectomy; ELH – Extended left hemihepatectomy; AR – Atypical resection
Source: created by the author

The most frequently modelled surgical option in patients without previous surgical interventions was extended right hemihepatectomy, accounting for 29.8% of cases. Extended right and extended left hemihepatectomy together comprised just under half of all cases (48.9%), indicating a high prevalence of extensive disease requiring resection of large liver volumes. Atypical resections were modelled in only 21.3% of cases, reflecting the need for an individualised surgical approach. Minimally invasive procedures, such as segmentectomy and sectorectomy, were modelled in only 4.2% of cases, confirming the limited applicability of organ-preserving surgery in the presence of extensive liver parenchymal involvement.

Among patients who had previously undergone surgical interventions, the most common types of VR resections were extended left hemihepatectomy (3 patients, 25%) and atypical resection (4 patients, 33.3%), indicating variability in the pattern of liver parenchymal involvement in most patients with progressive alveolar echinococcosis.

The mean future liver remnant volume in patients of the first group was 1,162 cm^3, compared with 774 cm^3 in the second group (Fig. 5). The median FLR volume was 1,074 cm^3 in Group 1 versus 628 cm^3 in Group 2. The standard deviation was 637.56 cm^3 in Group 1 and lower in Group 2 at 388.41 cm^3. The minimum FLR volume was 341 cm^3 in the first group and 181 cm^3 in the second group, while the maximum values were 2,804 cm^3 (Group 1) and 1,359 cm^3 (Group 2), respectively.

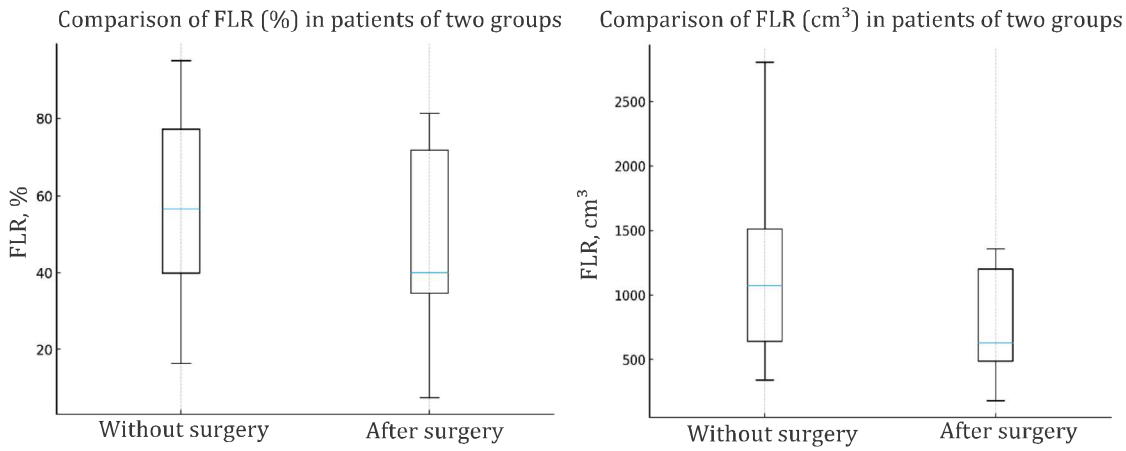

Figure 5. Box plot of future liver remnant volume in two patient groups in cm^3 and % during VR resections
Source: created by the author

The mean percentage of the future liver remnant (FLR) was 57.95% in Group 1 and 49.7% in Group 2. The median FLR percentage was 56.6% in Group 1 versus 40.1% in Group 2. The range of FLR values was 16.4–95.1% in Group 1 and 7.5–81.4% in Group 2. As expected, patients with a history of previous surgical interventions tended to have a smaller residual liver volume, which is attributable to the reduced amount of remaining liver tissue. The lower percentage FLR observed in the post-surgical group highlights the need for more meticulous planning of repeat interventions, as the risk of post-hepatectomy liver failure is higher in this group.

Discussion

The results of the present study demonstrate the high clinical relevance of CT volumetry with three-dimensional modelling in patients with alveolar echinococcosis of the liver. This method allows not only accurate assessment of the anatomical liver volume and the extent of parasitic involvement, but also virtual simulation of the planned resection volume, which substantially improves the accuracy of preoperative planning.

Additional confirmation of the clinical importance of assessing the future liver remnant in AEL is provided by recent studies focusing on methods of inducing hypertrophy of the liver parenchyma. In a retrospective series of 19 patients with advanced forms of AEL, portal vein embolisation (PVE) and two-stage hepatectomy (TSH) were shown to effectively increase the future liver remnant volume in cases with initially insufficient FLR [18]. Notably, neither the total liver volume nor the volume of parasitic involvement changed significantly after PVE, whereas the increase in FLR was pronounced, reaching a median growth rate of 4.49% per month after PVE and 3.34% per month after the first stage of TSH. The findings of the present study are consistent with these observations. In patients without previous surgical interventions, the mean FLR was 1,162 cm^3 (57.9%), reflecting preserved functional liver reserve despite extensive disease. In contrast, in patients after liver resections the mean FLR decreased to 774 cm^3 (49.7%), and in some cases reached borderline low values, potentially associated with a higher risk of postoperative liver failure. Comparison with published data on FLR hypertrophy rates after PVE suggests that, in patients with reduced FLR in the cohort, the use of hypertrophy-inducing techniques could have significantly improved the preoperative prognosis.

In a case series reported by H.D. Shen *et al.*, which included patients with multiple giant lesions of AEL, two-stage resections were successfully performed in all cases, with no mortality and no recurrences during follow-up exceeding one year [19]. The authors emphasised that the key limiting factor for radical treatment is a low FLR, and that an increase in the residual liver volume between stages makes curative resection feasible. These observations highlight an important characteristic of AEL: hypertrophy occurs predominantly in relatively preserved liver segments, while the total liver volume remains relatively stable due to the large proportion of non-functioning parasitic tissue.

In the majority of patients without previous surgical interventions, the mean future liver remnant volume was 1,162 cm^3, corresponding to 57.9% of the total liver volume. This value substantially exceeds the generally accepted safe FLR thresholds described for malignant liver tumours [20]. Numerous studies on liver resection for malignancies have shown that in patients with intact parenchyma it is sufficient to preserve 20–30% of the liver volume, whereas in the presence of fibrosis, steatosis, cirrhosis, or chemotherapy-induced liver injury, the minimum safe FLR increases to 30–40% and even 40–50% of the total liver volume [21]. Against this background, the FLR values obtained in the present study, both in patients without previous surgery (57.9%) and in previously operated patients (mean 49.7%), are well above the critical thresholds commonly applied in oncological practice.

Of particular interest are data reported in the literature on repeat liver resections for recurrent malignant lesions, where, similarly to AEL, the key parameter of preoperative planning is the future liver remnant (FLR). In a described clinical case of repeat resection for recurrent colorectal liver metastases, the non-congested FLR was only 34.9%, which was considered insufficient for safe surgery in view of prior chemotherapy and primary hepatectomy [22]. After portal vein embolisation and reconstruction of the right hepatic vein, the FLR increased to 58.0%, which made it possible to perform a repeat bisegmentectomy without the development of post-hepatectomy liver failure. This example highlights that an FLR below 30–40% in patients undergoing repeat interventions is critical and requires mandatory use of strategies aimed at increasing the functionally active residual liver volume [23]. In a similar manner, the present results demonstrate that in one third of patients after surgery for AEL, the FLR was below the recommended threshold, necessitating more in-depth preoperative assessment and potential application of liver hypertrophy induction techniques.

Despite the widespread use of anatomical CT volumetry, the findings of the present study are consistent with reports emphasising that the absolute anatomical FLR does not always correlate with the risk of postoperative liver failure. In the study by M. Serenari *et al.* [24] functional FLR (FLR-F) was shown to be a more accurate predictor of post-hepatectomy liver failure, with threshold values significantly higher than the classical “50/50 criteria”. Nearly half of the patients developed post-hepatectomy liver failure after major resections despite having an anatomically acceptable FLR, underscoring the importance of assessing the functional viability of the liver parenchyma. These data support the need to apply functional assessment methods, particularly in patients with chronic inflammatory liver diseases, in whom anatomical volume does not always reflect the true functional reserve of the organ. For comprehensive surgical risk assessment, volumetric analysis should be combined with functional methods, such as hepatobiliary scintigraphy with 99mTc-mebrofenin or functional MRI with Gd-EOB-DTPA contrast enhancement. This approach is especially relevant in patients with fibrosis, steatosis, or those undergoing repeat surgical interventions [25].

Taken together, the obtained data confirm that CT volumetry with calculation of the total liver volume and the future liver remnant is a key tool in preoperative planning for patients with alveolar echinococcosis of the liver. In the majority of non-operated patients, compensatory enlargement of the total liver volume and a relatively high FLR are observed, creating more favourable conditions for performing radical surgical interventions. In contrast, in patients with previous liver resections the FLR is significantly reduced, and in some cases reaches critical values, which markedly increases the risk of developing postoperative liver failure.

Despite the widespread use of anatomical FLR assessment, international data indicate that functional evaluation of the future liver remnant (for example, using Gd-EOB-enhanced MRI) is a more accurate predictor of postoperative liver failure, particularly in patients with chronic liver disease. However, at present these methods are virtually unavailable in the Kyrgyz Republic due to the lack of specialised equipment. As a result, clinical practice is largely based on anatomical FLR parameters, which inevitably limits the accuracy of prognostic assessment. The results obtained highlight the need for further development of functional liver radiology in the Kyrgyz Republic, implementation of quantitative functional assessment techniques, and expansion of diagnostic capabilities in order to improve the safety of surgical treatment.

Thus, anatomical CT volumetry combined with resection modelling remains the most objective tool for selecting the optimal surgical strategy in settings with limited resources; nevertheless, the pursuit of integrating functional assessment methods represents an important objective for improving the quality of care for patients with alveolar echinococcosis of the liver.

Conclusions

CT volumetry with three-dimensional modelling enables accurate determination of the extent of liver involvement and prediction of the residual parenchymal volume, which is critically important for planning surgical treatment in AEL. In patients without previous surgical interventions, the mean future liver remnant volume exceeds safe threshold values, whereas in patients who have undergone liver resections a significant reduction in FLR volume is observed, increasing the risk of postoperative complications.

The wide range of FLR values and their high variability emphasise the need for individualised surgical planning. Virtual resection improves the accuracy of residual liver volume calculation and facilitates selection of the optimal surgical strategy. Functional liver assessment methods (hepatobiliary scintigraphy, functional MRI with Gd-EOB-DTPA) should be used in addition to volumetric analysis, especially in patients with chronic liver disease or those undergoing repeat interventions. Thus, CT volumetry with three-dimensional modelling should become an integral component of preoperative planning in AEL, particularly in cases requiring extensive or repeated resections.

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Conflict of Interest

The author declares no conflict of interest. There are no personal, financial, or other relationships that could have influenced the results of the study.

References

[1] Fengming Y, Zhang W, Feng L. Efficacy and safety of different options for liver regeneration of future liver remnant in patients with liver malignancies: a systematic review and network meta–analysis. World J Surg Oncol. 2022;20(1):399. Published 2022 Dec 16. DOI: 10.1186/s12957–022–02867–w

[2] Aliseda D, Rotellar F, Sancho L, Batidas JF, Martínez de la Cuesta A, Rodríguez–Fraile M. Surgery and radioembolization of liver tumors. Rev Esp Med Nucl Imagen Mol (Engl Ed). 2023;42(4):265–71. DOI: 10.1016/j.remnie.2023.06.002

[3] Mousa AA, Mohammed AM, El–Mohandes MI, Ahmed RG. The fetal liver volume assessment by three–dimensional ultrasound as a parameter to monitor fetal growth. Med J Cairo Univ. 2022;90(3):351–8. DOI: 10.21608/mjcu.2022.235034

[4] Sivayogaraj K, Guruge ST, Liyanage U, Udupihille J, Jayasinghe S, Fernando G, et al. LiverUSRecon: Automatic 3D reconstruction and volumetry of the liver with a few partial ultrasound scans. In: Med Image Comput Comput Assist Interv (MICCAI) 2024. Lect Notes Comput Sci (LNCS). Cham: Springer; 2024. 436–45. DOI: 10.1007/978–3–031–72104–5_42

[5] Smit JN, Kuhlmann KFD, Thomson BR, Kok NFM, Fusaglia M, Ruers TJM. Technical note: Validation of 3D ultrasound for image registration during oncological liver surgery. Med Phys. 2021; 2021;48(10):5694–701. DOI: 10.1002/mp.15080

[6] Primavesi F, Maglione M, Cipriani F, Denecke T, Oberkofler CE, Starlinger P, et al. E–AHPBA–ESSO–ESSR Innsbruck consensus guidelines for preoperative liver function assessment before hepatectomy. Br J Surg. 2023;110(10):1331–47. DOI: 10.1093/bjs/znad233

[7] Smet H, Martin D, Uldry E, Duran R., Giradet R, Schaefer N, et al. Tc–99m mebrofenin hepatobiliary scintigraphy to assess future liver remnant function before major liver surgery. J Surg Oncol. 2023;128(8):1312–9. DOI: 10.1002/jso.27426

[8] Li C, Liu H, Wang J, Li X, Cui T, Wang R, et al. Multiparametric MRI combined with liver volume for quantitative evaluation of liver function in patients with cirrhosis. Diagn Interv Radiol. 2022;28(6):547–54. DOI: 10.5152/dir.2022.211325

[9] Wang YY, Zhang J, Zhuang X, Jin QY, Liu LQ. Gadolinium-ethoxybenzyl-diethylenetriamine pentaacetic acid-enhanced MRI improves diagnosis and efficacy evaluation of early-stage hepatocellular carcinoma. Am J Cancer Res. 2024;14(10):4855–67. DOI: 10.62347/WYNK6968

[10] Graeter T, Shi R, Bao H, Liu W, Jiang Y, Schmidberger J, et al. Intrahepatic manifestation and distant extrahepatic disease in alveolar echinococcosis: A multicenter cohort study. Acta Radiol. 2021;62(8):997–1005. DOI: 10.1177/0284185120951958

[11] Vuitton DA, McManus DP, Rogan MT, Rogan MT, Roming T, Gottstein B, et al. International consensus on terminology to be used in the field of echinococcoses. Parasite. 2020;27:41. DOI: 10.1051/parasite/2020024

[12] Zhang J, Dawa, Suolang D, Lei Y, Wang J, Basang D. The application of preoperative three–dimensional reconstruction visualization digital technology in the surgical treatment of hepatic echinococcosis in Tibet. Front Surg. 2021;8:715005. DOI: 10.3389/fsurg.2021.715005

[13] Zhang H, Zhang L, Zhang C, Zhu YH, Hong YE, Li L, et al. CT imaging features and diagnostic algorithm for hepatic cystic echinococcosis. Sci. Rep. 2025;15(1):10671. DOI: 10.1038/s41598–025–94860–y

[14] Miki A, Sakuma Y, Watanabe J, Endo K, Sasanuma H, Teratani T, et al. Remnant liver function is associated with long-term survival in patients with hepatocellular carcinoma undergoing hepatectomy. Sci. Rep. 2023;13(1):15637. DOI: 10.1038/s41598–023–42929–x

[15] Nagayama Y, Hokamura M, Taguchi N, Yokota Y, Osaki T, Shiraishi S, et al. Liver function estimation using multiphase hepatic CT: Diagnostic performance of iodine-uptake and volumetric parameters. Eur Radiol. 2025;35(9):5781–91. DOI: 10.1007/s00330–025–11497–1
[16] Voskanyan SE, Chuchuyev ES, Artemiyev AI, Zabezhinsky DA, Bashkov AN, Zhurbin VS, et al. Associated Liver Partition and Portal vein ligation for Staged hepatectomy (ALPPS) in focal liver diseases management. Pirogov Russ J Surg. 2018;2:39–44. DOI: 10.17116/hirurgia2018239–44
[17] Wen H, Vuitton L, Tuxunet T, Li J, Vuitton DA, Zhang W, at al. Echinococcosis: Advances in the 21st century. Clin. Microbiol. Rev. 2019;32(2):e00075–18. DOI: 10.1128/CMR.00075–18
[18] Guo Q, Wang M, Zhong K, Li J, Jiang T, Ran B, et al. Application of hepatic lobe hyperplasia techniques in the treatment of advanced hepatic alveolar echinococcosis: A single-centre experience. BMC Surg. 2022;22(1):415. DOI: 10.1186/s12893–022–01864–w
[19] Shen HD, Chen KF, Li B, Zhang HZ, Yang KM, Chen Y, et al. Two-stage hepatectomy for multiple giant alveolar echinococcosis. Med. 2017;96(33):e7819. DOI: 10.1097/MD.0000000000007819
[20] Reese T, Gilg S, Böcker J, Wagner KC, Vail M, Engstrand J, et al. Impact of the future liver remnant volume before major hepatectomy. Eur J Surg Oncol. 2024;50(11):108660. DOI: 10.1016/j.ejso.2024.108660
[21] Guglielmi A, Ruzzenente A, Conci S, Valdegamberi A, Iacono C. How much remnant is enough in liver resection? Dig Surg. 2012;29(1):6–17. DOI: 10.1159/000335713
[22] Matsuki R, Momose H, Kogure M, Suzuki Y, Sakamoto Y. Bisegmentectomy and venous reconstruction after portal vein embolization for the remnant hemiliver in a patient with recurrent colorectal liver metastases. Ann Gastroenterol Surg. 2020;5(2):259–64. DOI: 10.1002/ags3.12393
[23] Gavriilidis P, Marangoni G, Ahmad J, Azoulay D. Simultaneous portal and hepatic vein embolization is better than portal embolization or ALPPS for hypertrophy of future liver remnant before major hepatectomy: A systematic review and network meta-analysis. Hepatobiliary Pancreat Dis Int. 2023;22(3):221–7. DOI: 10.1016/j.hbpd.2022.08.013
[24] Serenari M, Bonatti C, Zanoni L, Peta G, Tabacchi E, Cucchetti A, et al. The role of hepatobiliary scintigraphy combined with spect/ct in predicting severity of liver failure before major hepatectomy: A single-center pilot study. Updates Surg. 2021;73(1):197–208. DOI: 10.1007/s13304–020–00907–2
[25] Tsuruga Y, Kamiyama T, Kamachi H, Orimo T, Shimada S, Nagatsu A, et al. Functional transition: Inconsistently parallel to the increase in future liver remnant volume after preoperative portal vein embolization. World J Gastrointest Surg. 2021;13(2):153–63. DOI: 10.4240/wjgs.v13.i2.153