

Jerusalem Artichoke Powder Mixed in Enteral Feeding for Patients Who have Diarrhea in Surgical Intensive Care Unit: A Method of Preparation and a Pilot Study

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ABSTRACT

Aim and objective: The Jerusalem artichoke (*Helianthus tuberosus* L.) is a tuber with high soluble fiber. The objective of this study was to demonstrate the method of preparation and pilot test this substance as an additive to enteral feeding.

Materials and methods: We processed Jerusalem artichoke into a 600 micrometers powder, tested its properties, and pilot tested its use in patients who had diarrhea (King's stool score ≥ 12) in a surgical intensive care unit. Two grams of Jerusalem artichoke powder were mixed in each 100 mL of hospital enteral feeding formula and administered for 5 days.

Results: Artichoke powder slightly increased the viscosity of enteral feeding formula. The dietary fiber content of the mixture was 20.8–21.6 g% and the content of fructans was 66.0–71.5 g%. In the pilot study in 11 patients, diarrhea was improved (diarrhea score < 12) in 7/11 (63.6%) patients by day 5. Improvement in diarrhea started on day 2 [median different diarrhea score (interquartile range): -4 (-8 to 0); $p = 0.03$] and peaked by days 4 and 5 [-7 (-10 to -3); $p < 0.01$ and -8 (-12 to -4); $p < 0.01$, respectively]. There were no complications during the study except three patients had a high gastric residual volume (> 200 mL).

Conclusion: Processed powder of Jerusalem artichoke tuber has a high fiber content and increases viscosity of enteral feeding solutions only slightly. When administered as part of enteral nutrition to critically ill surgical patients, the diarrhea score improves in most patients.

Keywords: Diarrhea, Fructans, Jerusalem artichoke, Soluble fiber, Surgical critically ill.

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INTRODUCTION

Jerusalem artichoke (*Helianthus tuberosus* L.), called Kaen-ta-wan in Thai, is a tuber crop widely cultivated in the northern and northeastern regions of Thailand.¹ It is comprised of a high proportion of soluble fiber including inulin and oligofructose.² Our previous report in surgical critically ill septic patients demonstrated that a fiber-enriched diet decreases the diarrhea score.³ Although the difference in the incidence of diarrhea was lower in the study group (mixed fiber 23.5% and control 47.1%), this study did not show a statistically significant effect due to the small number of enrolled subjects.³ In Thailand, there are differences in hospital preparations of enteral feeding formulas. In our nutrition department service, the standard hospitalized formula is a mixture of pumpkin, chicken meat, egg, and soy oil. These macronutrient ingredients contain 12% protein, 50–55% carbohydrate, 33–38% fat, and a very low amount of fiber. The mixing of artichoke into an enteral feeding formula could increase the amount of soluble fiber. However, artichoke is a seasonal crop. The processing of artichokes into dry power could create a continuous supply. The objective of this study was to describe the process of producing artichoke powder, measure the physical properties and amount of fiber in an artichoke-enriched enteral feeding formula, and to measure the effect of this mixture on diarrhea in patients who are admitted to a surgical intensive care unit (SICU).

MATERIALS AND METHODS

Processing of Artichoke into Powder

The artichokes were harvested from an artichoke farm in Chiang Mai, Thailand. The artichoke processing is summarized in Flowchart 1.

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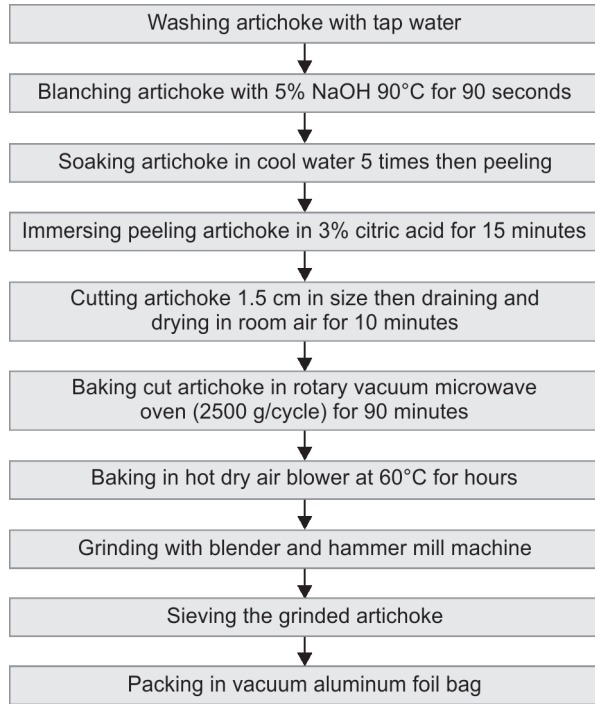
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Conflict of interest: None

After cleaning the artichokes with tap water, they were blanched with 5% sodium hydroxide at 90°C for 90 seconds, rinsed five times in cool water, and then cooled at room temperature and peeled. The peeled artichokes were immersed into 3% citric acid for 15 minutes, then cut into 1.5 cm pieces. The cut artichokes were left at room air to drain for 10 minutes. Then they were dried in a rotary vacuum microwave oven for 90 minutes (vacuum microwave dryer, March Cool Co., Ltd Thailand) until the moisture content was less than 15%. The products were dried again in a hot dry air oven (Hot air dryer,

Flowchart 1: Processes for Jerusalem artichoke powder production

Memmert, Germany) at 60°C for 4 hours. The dried products were ground with a blender and hammer mill machine, and then sieved to retain particles that were 600 micrometers in size (Sieve shaker, Restex, UK). Finally, the dried powder of artichoke was packed in a vacuum aluminum foil bag and refrigerated at 2–4°C.

Physical and Chemical Measurements

The physical characteristics of artichoke powder were investigated by collaborators at the Faculty of Agro-Industry, Chiang Mai University, Chiang Mai, Thailand. The total amount of raw material per total yield product by weight was recorded [% yield = (weight of dry powder/weight of raw material) × 100]. The moisture content was reported in percent by weight. The water activity (a_w) was measured by Aqua LAB (Model Series 3, Decagon Device Inc., USA) (a_w = equilibrium relative humidity (ERH)/100). The color of the artichoke powder was reported according to the Commission Internationale de l'Eclairage (CIE) system, which included L^* (lightness), a^* (redness), and b^* (yellowness), which were measured by a colorimeter (Konica-Minolta, Model CR-410, Japan). The viscosity and solubility were measured by a rapid viscosity analyzer (RVA) and a texture analyzer (TA) [Brookfield (model DV-II+ viscometer)] and was reported in rapid visco unit (RVU). The composition of dietary fiber and fructans (inulin and oligofructose) was measured according to the method of the association of official analytical chemists (AOAC, 2016, method No. 985.29 and 997.08, respectively) (at Institute of nutrition, Mahidol University, Nakorn Pathom, Thailand).^{4,5}

Pilot Enrollment and Intervention

This study was a single arm design, before and after intervention study. The objective of this pilot study was to measure the clinical effects of processing Jerusalem artichoke in powder form to mix in an enteral feeding formula for patients who had diarrhea in a SICU. This study was approved by the Ethics Committee, Faculty of

Medicine, Chiang Mai University (Study code number: SUR-2557-02376). All participants provided a written informed consent prior to participation. All the enrolled patients were more than 18 years of age, had stable hemodynamic measurements, were receiving an enteral diet via nasogastric tube, were tolerating at least 60% of that diet without interruption, and who had a diarrhea score greater than 12 by the King's stool chart. We excluded patients who were receiving medications that might cause diarrhea such as metoclopramide, quinidine, xylitol, magnesium, erythromycin, and aminophylline; we also excluded patients who needed an enema for any cause. Patients who were had infectious diarrhea or who had undergone a total colectomy or ileostomy were excluded.

After patient consent, the processed artichoke was mixed into the enteral formula in the amount of 2 g/100 mL (20 g/L) and administered for 5 days. The enteral formula was an isoosmotic blended diet (1 kcal/mL). All patients were fed using a continuous drip-feeding protocol. In this protocol, the feeds were started at the rate of 25 mL/hour and then increased every 4–5 hours, provided the gastric residual volume was less than 200 mL, until the target feeding rate was achieved (25–30 kcal/kg/day). The osmolarity and the pH of the feeding formula were the same before and after adding the artichoke powder. The pHs between the plain and after mixing formula were the same in range. The study protocol gave the processed artichoke for only 5 days. In this study, all patients were fed using the continuous drip-feeding protocol. In this protocol, the feeds were started at the rate of 25 mL/hour and then increased every 4–5 hours—provided the gastric residual volume was less than 200 mL, until feeding target was achieved. There were no changes in medications after beginning the artichoke-enriched formula. Blood tests including complete blood count, blood urea nitrogen, serum creatinine, electrolyte, liver function tests, and glucose were obtained within 24 hours before receiving the artichoke-enriched formula, and after receiving it for 5 days. We recorded complications including vomiting and tube clogging or obstruction. The gastric residual volume was regularly measured every 4 hours (30 times in 5 days). We also recorded the severity of disease and comorbidity at the time of initiation and the daily sum of diarrhea score.

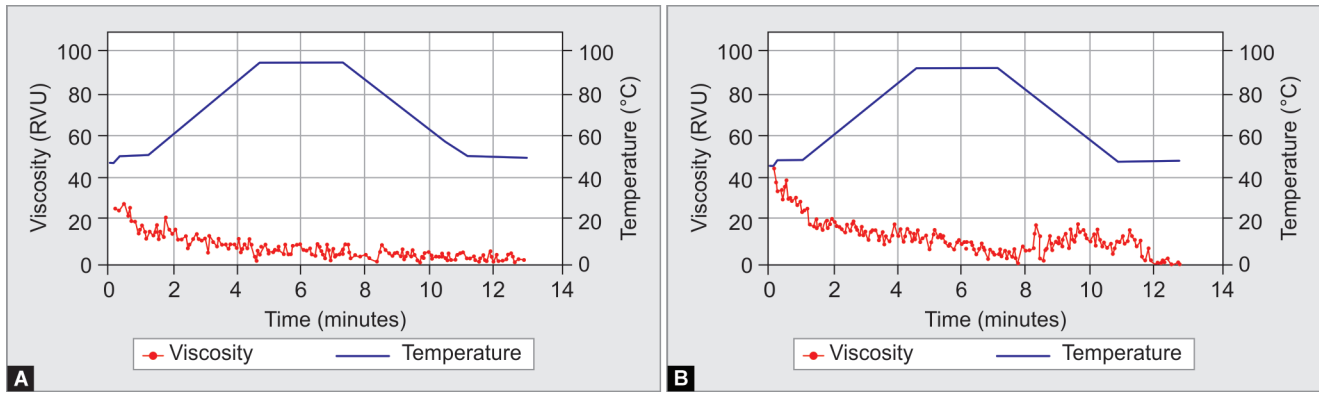
Statistical Analysis

The before and after laboratory values were compared using the paired *t* test and the Wilcoxon sign-rank test for parametric and nonparametric distribution, respectively. The continuous variables were reported as mean (standard deviation, SD) or median (interquartile range, IQR) for normal and nonnormal distribution, respectively. The significant statistical difference was *p* value <0.05.

RESULTS

Physical Property and Dietary Fiber Profile after Processing

The product yield of processed Jerusalem artichoke was 10.3–12.6%. The moisture content was 3.1–3.3% and water activity (a_w) was 0.39–0.40. The color values by L^* , a^* , and b^* were 65.8–66.1, 7.6–7.7, and 20.8–21.6, respectively. Regarding the viscosity analysis (Fig. 1 and Table 1), the pasting curve or viscosity curve (Fig. 1) demonstrated that the peak viscosity of 5 and 10% artichoke powder were 0.2–0.3 minutes, the peak viscosities were 210 and 275 RVU, respectively (Table 1). The viscosity curves were significantly decreased after 0.5 minute and viscosities less than 50 RVU were independent of



Figs 1A and B: Pasting curve: (A) 5% of artichoke by weight; (B) 10% of artichoke by weight

Table 1: Jerusalem artichoke properties after processing

Property	Value
Processing weight per 100 g of raw weight (% yield)	10.3–12.6
Physical properties of processed artichoke	
Moisture content (%)	3.1–3.3
Water activity (a_w) [†]	0.39–0.40
Color L* (lightness) [‡]	65.8–66.1
Color a* (redness) [‡]	7.6–7.7
Color b* (yellowness) [‡]	21.7–20.8
Peak (at 95°C)/lowest (at 95°C)/ final viscosity of pasting curve (RVU)	
5% artichoke powder	8/0.5/0.3
10% artichoke powder	14/3.0/0.6
Viscosity change after mixing 2 g in 100 mL enteral feeding formula at 21–22°C (RVU)	0.6–0.7
Fiber contents of processed Jerusalem artichoke powder (g/100 g)	
Total dietary fiber	20.8–21.6
Insoluble fiber	5.0–5.2
Soluble fiber	15.8–16.4
Fructans (inulin + oligofructose)	66.0–71.5
Total soluble fiber (fructans + dietary soluble fiber)	81.8–87.9

[†] a_w equilibrium relative humidity (ERH)/100

[‡]Color measurement: L*, lightness; a*, redness; b*, yellowness (standard values of L*, a*, b* = 46.24, 2.80, 18.24)

temperature (Fig. 1). These results indicated that the swelling of artichoke particles in the powder was very low. These hypotheses were confirmed by observing that the viscosity of the artichoke-enriched enteral feeding formula increased by only 0.6–0.7 RVU. The dietary fiber content of the artichoke-enriched formula was 20.8–21.6 g/100 g (5.0–5.2 of insoluble fiber and 15.8–16.4 soluble fiber), and the fructan content (inulin and oligofructose) was 66.0–71.5 g/100 g.

Patient Outcomes of Pilot study

Eleven patients were enrolled into the pilot study between June 2016 and June 2017. Six patients (54.5%) were male. The mean age (standard deviation, SD) was 67.2 (11.7) years, the mean APACHE II score at admission (SD) was 16.8 (3.7), and the mean body mass index (SD) was 20.7 (2.5). Eight patients (72.7%) were postoperative

(Table 2). Sepsis was the reason for ICU admission in 72.7%. The comorbidities were diabetic mellitus (6/11, 54.5%), hypertension (3/11, 27.2%), malnutrition (3/11, 27.2%), and acute kidney injury (3/11, 27.2%).

At enrollment and before administration of the artichoke-enriched formula, the median (IQR) of the diarrhea score was 18 (12–26) (Fig. 2). The median diarrhea score decreased after the artichoke-enriched formula was started. This effect of improvement started on day 2 [median different diarrhea score (IQR): –4 (–8 to 0); $p = 0.03$] and peaked by days 4 and 5 [–7 (–10 to –3); $p < 0.01$ and –8 (–12 to –4); $p < 0.01$, respectively]. At the end of study on day 5, the proportion of patients whose diarrhea score was less than 12 was 63.6% (7/11). There were no reports of vomiting or tube clogging during the study period. Only three patients had gastric residual volume more than 200 mL (7 times/total 220 residual measurements; Table 3). Although the intensive care mortality was high at 36.3% (4/11), the causes of death were associated with disease process (sepsis with multi-organ dysfunction in two patients, respiratory failure in one patient, and late surgical complication in one patient) and were not associated with the study intervention. The laboratory results of complete blood count, blood chemistry, and liver function were not statistically different except serum sodium and chloride, which were slightly lower than before receiving artichoke-enriched formula at day 5 (Table 4).

DISCUSSION

This study demonstrates the method of processing Jerusalem artichoke into powder, its properties, and the amount of fiber contained in the artichoke-enriched formula. Regarding the physical properties, the peak viscosity is the highest viscosity measured at temperature of 95°C. This value is associated with the powder swelling and granule disruption rate.⁶ The hold viscosity is the lowest viscosity achieved during heating at 95°C. This value means the viscosity changes from the disruption of the powder.⁶ The final viscosity is the mixing viscosity after temperature lowers to 50°C. This number indicates the restructuring and retrograding of starch molecules. It refers to the ability of the powder to form the gelatinous paste after cooling.⁶ The high, medium, and low viscosities are classified as >300, 200–300, and <200 RVU, respectively.⁶ Our results demonstrate that gelatinous forming was low. The peak, holding, and final viscosities were low (<200 RVU). These properties led to the very low alteration of viscosity after mixing of 2 g powder in 100 mL of the enteral feeding formula, as well as no report of tube clogging during feeding of the patients.

Table 2: Patient characteristics

Case	Age	Gender	APACHE II	BMI	Diagnosis	Procedure	ICU admission reason	Comorbidity
1	66	Male	22	24.1	Fournier gangrene	Debridement	Sepsis	DM, HT
2	56	Female	12	22.9	Lung cancer	VAT lobectomy	Postoperation	DM
3	74	Female	21	21.1	Acute cholecystitis	Open cholecystectomy	Sepsis	DM, HT, AKI
4	69	Female	14	22.9	Pneumonia	—	Sepsis	DM
5	82	Female	16	20.7	Acute colitis	—	Sepsis	HT
6	57	Male	18	18.0	Lung cancer with pneumonia	VAT pleurodesis	Sepsis	Malnutrition
7	48	Male	12	17.1	Pneumonia	—	Sepsis	Malnutrition
8	77	Male	15	21.5	Acute cholecystitis	Open cholecystectomy	Sepsis	HT
9	82	Female	14	17.3	Small bowel obstruction	Explore laparotomy	Postoperation	Malnutrition
10	55	Male	21	22.8	Necrotizing fasciitis	Debridement	Sepsis	DM, cirrhosis, AKI
11	73	Male	20	19.0	Abdominal aortic aneurysm	Open repair AAA	Postoperation	DM, HT, AKI

AAA, abdominal aortic aneurysm; APACHE II, acute physiologic and chronic health evaluation II score; AKI, acute kidney injury; BMI, body mass index; DM, diabetic mellitus; HT, hypertension; VAT, video-assisted thoracoscope

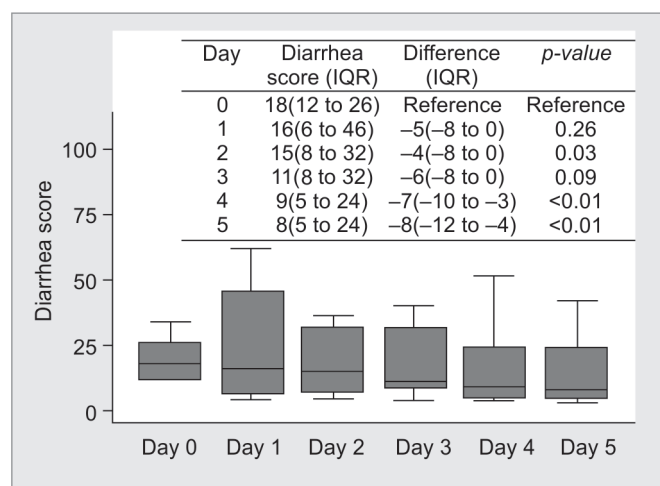


Fig. 2: Diarrhea score before (day 0) and after (days 1–5) artichoke mixed blenderized enteral feeding

The Jerusalem artichoke tuber contains highly soluble fiber. In a fresh sample, the sum of dietary fiber is around 25 g/100 g fresh weight (FOS 5.16 g and inulin 19.4 g).⁷ After processing, the total soluble fiber increased to 81.8–87.9 g/100 g of dried powder. This figure is comparable to the hydrolyzed guar gum. Yoon et al. reported that the partially hydrolyzed guar gum has 75 g% of soluble fiber.⁸ There is no consensus recommendation on the appropriate amount of fiber in enteral formulas. However, since the year 2000, enteral formula mixed with different sources of fiber has been reported in randomized control trials in critically ill patients (Table 5). However, the fiber doses varied from 2.6 to 22 g/L^{3,9–14} and 9 to 22 g/L in adults.^{3,9–12,14} These formulas comprised of different soluble fiber in the ranges of 2.6–16.5 g/L^{3,9–14} and 3.75–16.5 g/dL^{3,9–12,14} in adults. In our study, the amount of fiber with artichoke powder was provided in the range of previous reports of 16.4–17.6 g of soluble fiber/L.

In our pilot study in 11 patients in surgical ICU, diarrhea improved in 63.6%. The diarrhea score improved after the 2nd day (Table 3 and Fig. 2). There were no complications during feeding except high gastric residual volume (GRV), which led to the interruption of enteral feeding. We also used the cut-off point as

200 mL in our institute guidelines due to the small body phenotype of Thai people and Thai recommendations to use 200–250 mL in patients who are receiving enteral feeds.^{15,16} The reduction of diarrhea after giving the soluble fiber might be explained from microbiota alterations. O’Keefe et al. reported the quantitative polymerase chain reaction (qPCR) of microbial 16S rRNA genes and Human Intestinal Tract Chip (HITChip) microarray analysis after giving soluble fiber to critically ill patients. Fiber supplements were found to create a significant increase in fecal short-chain fatty acid and microbial counts of specific butyrate producers. These resulted in the resolution of diarrhea in three of four of his enrolled patients.¹⁷ However, the results of using fiber-containing enteral formula in critically ill patients are still inconsistent.^{18,19} The American Society of Parenteral and Enteral Nutrition (ASPEN) guidelines mention that “we suggest that a commercial mixed fiber formula not be used routinely in the adult critically ill patient prophylactically to promote bowel regularity or prevent diarrhea”¹⁸ and “based on expert consensus, we suggest considering use of a commercial mixed fiber-containing formulation if there is evidence of persistent diarrhea.”¹⁸ In a recent systematic review of dietary fibers in enteral nutrition of critically ill patient in eight studies, it was concluded that soluble fiber is safe in all hemodynamically stable intensive care unit patients.²⁰ The fiber-containing formula may be beneficial for decreasing gastrointestinal symptoms especially diarrhea and may assist in treatment in this group of patients.²⁰ However, further studies are required to answer the routine use of an enriched fiber diet in critically ill patients.²⁰

There were no statistically significant differences in laboratory tests between before and after artichoke powder administration except serum sodium and chloride levels. But these differences were not clinically significant. In addition, these findings might be confounded by concomitant fluid therapy during the study period.

In addition to describing the production process, this study is a pioneer clinical study using the Jerusalem artichoke as a source of dietary fiber in surgical critically ill patients. However, there were some limitations in this study. First, because of no previous studies of similar products, we performed a pilot study to investigate the potential benefit in patients suffering from diarrhea. The small sample size and non-randomization without control arm led to insufficient power and random bias effects. However, the results of this study showed the mixing of artichoke powder into hospital

Table 3: Clinical outcomes

Case	Diarrhea score				Enteral feeding complications			ICU discharge status
	Day 1	Day 5	Range [†]	Improvement [‡]	Vomiting	Tube clogging	GRV > 200 mL (times)	
1	12	8	(6–8)	Yes	No	No	No	Nonsurvived
2	12	5	(4–6)	Yes	No	No	Yes (1)	Nonsurvived
3	16	10	(10–15)	Yes	No	No	No	Survived
4	18	6	(8–13)	Yes	No	No	Yes (4)	Nonsurvived
5	34	24	(24–46)	No	No	No	No	Survived
6	15	3	(4–16)	Yes	No	No	No	Survived
7	26	24	(24–32)	No	No	No	Yes (2)	Survived
8	18	8	(8–16)	Yes	No	No	No	Survived
9	110	42	(32–52)	No	No	No	No	Survived
10	12	4	(4–6)	Yes	No	No	No	Survived
11	24	20	(20–32)	No	No	No	No	Nonsurvived

[†]Range of diarrhea score between 2nd and 5th day

[‡]Score < 12 at 5th day; GRV, gastric residual volume

Table 4: Laboratory tests before and after receiving artichoke-enriched enteral feeds

Laboratory	Before	(SD)	After	(SD)	p value
Complete blood count					
Hemoglobin (g/dL)	9.2	(0.9)	9.3	(0.6)	0.90
Hematocrit (%)	28.1	(2.7)	28.4	(1.8)	0.68
White blood cell count (×10 ³ /mL)	10.7	(4.2)	12.8	(4.3)	0.10
Neutrophil (%)	80.4	(9.2)	79.0	(8.9)	0.38
Lymphocyte (%)	10.8	(6.4)	11.4	(5.2)	0.64
Platelet (×10 ³ /mL)	195.4	(89.0)	245.5	(100.6)	0.06
Blood chemistry					
Blood urea nitrogen (mg/dL)	37.1	(18.0)	36.3	(24.6)	0.86
Creatinine (g/dL)	2.2	(2.0)	2.2	(2.2)	0.33
Sodium (mEq/L)	143.9	(14.8)	138.9	(10.4)	0.03
Potassium (mEq/L)	3.9	(0.6)	3.7	(0.5)	0.12
Chloride (mEq/L)	106.7	(8.5)	102.4	(6.2)	0.03
Bicarbonate (mEq/L)	21.2	(2.8)	21.7	(1.2)	0.65
Glucose (mg/dL)	139.7	(35.4)	136.5	(32.0)	0.72
Liver function test					
Total bilirubin (mg/dL)	0.8	(0.3)	0.8	(0.3)	0.81
Direct bilirubin (mg/dL)	0.5	(0.3)	0.5	(0.3)	0.86
Albumin (mg/dL)	2.5	(2.1)	2.1	(0.8)	0.23
Aspartate aminotransferase (U/L)	31.6	(14.2)	33.1	(13.0)	0.39
Alanine aminotransferase (U/L)	25.8	(34.0)	26.5	(33.7)	0.42
Alkaline phosphatase (U/L)	194.3	(249.1)	195.5	(248.4)	0.28
Cholesterol (mg/dL)	87.8	(35.3)	90.2	(34.7)	0.25

Table 5: Amount of fiber in enteral formula in critically ill in previous and current study

First author (year)	Type of fiber	Enrolled patients	Soluble (g/L)	Insoluble fiber (g/L)
Caparros et al. (2001)	9 g/L of mixed fiber	Adults	3.75	5.25
Spapen et al. (2001)	22 g/L of guar gum	Adults	16.5 [†]	—
Rushdi et al. (2004)	22 g/L of guar gum	Adults	16.5 [†]	—
Spidler-Vesel et al. (2007)	22 g/L of guar gum	Adults	16.5 [†]	—
Chittawatanarat et al. (2010)	15 g/L of mixed fiber	Adults	7.5	7.5
Simakachorn et al. (2011) [‡]	2.6 g/L of inulin/FOS	Pediatrics	2.6	—
Yagmurdur et al. (2016)	15 g/L of mixed fiber	Adults	7.0	8.0
Current study	20 g/L of artichoke powder	Adults	16.4–17.6	1.0–1.1

[†]Estimated by calculate soluble fiber in hydrolyzed guar gum is at least 75%⁸

[‡]Study in pediatric critically ill patient; FOS, fructo-oligo saccharide

formula was safe in terms of feeding processes (vomiting and tube clogging) with small occurrence of GRV >200 mL. Second, nearly two-thirds of patients had improved diarrhea symptoms but we had no data about intestinal physiological and biological alterations such as motility and gut microbiota. Future studies should investigate these issues.

CONCLUSION

The processed powder of Jerusalem artichoke tuber mixing in hospital enteral feeding formula slightly alters the viscosity of enteral feeds, and mixed Jerusalem artichoke formula may improve the diarrhea score in surgical critically ill patients. However, a future large randomized control trial should be performed to validate these results.

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