Capstone Cover Page

Weber State University Bachelor of Integrated Studies Program

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Title: Nutrient Absorption in BCIR Patients

Brief Summary of Project: Research has been done on nutrients that may result in deficiency for patients with a Barnett Continent Intestinal Reservoir. Determination of risk for deficiency is based on risk in patients with similar medical procedures. A brochure for hospital use to inform patients of these possible deficiencies has been created and included.

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NUTRIENT ABSORPTION IN BCIR PATIENTS

Abstract

Nutrient absorption can become a problem in patients whose gastrointestinal tract has been subject to disease or surgical procedure. The Barnett Continent Intestinal Reservoir (BCIR) is a procedure in which the colon is removed and the ileum is formed into a pouch inside the patient’s body. Research has been done on nutrient absorption in short bowel and proctocolectomy patients, but not specifically on the BCIR patient.

Seven vitamins (vitamin A, D, E, K, and B₁₂, thiamin, and folate), seven minerals (sodium, chloride, potassium, magnesium, iron, zinc, and selenium), and fiber have been investigated through research that has previously been completed on short bowel and proctocolectomy patients. This investigation has been used to infer whether these vitamins and minerals would pose a nutritional issue in BCIR patients.

A high risk of developing deficiencies in iron and vitamin B₁₂ in BCIR patients has been found through the investigation conducted. There is moderate risk of developing deficiencies in the fat-soluble vitamins (A, D, E, and K), sodium, chloride, and magnesium. There is little risk of developing deficiencies in thiamin, folate, potassium, zinc, and selenium. Additionally, patients with a BCIR may need less fiber in their diet.

These patients should be aware of the possibility of deficiency and the role of fiber so they can monitor their medical condition and know when to address these issues with a physician. There is variation in the way a person’s body reacts to trauma and nutrient intake, which must be taken into account in each patient’s case. Patients should be informed of these findings in a way that makes sense to them, and a brochure has been created for this purpose.
Introduction

The human gastrointestinal tract involves a complex process of ingestion, digestion, absorption of nutrients and excretion of solid waste. Food is chewed in the mouth, becomes bolus, and travels through the esophagus into the stomach (Figure 1). It is there that the bolus is produced into chyme, which consists of partially digested food and gastric juices. In the stomach proteins are also denatured, lose their three-dimensional structure, by hydrochloric acid and are prepared for digestion. Chyme is slowly released from the stomach into the small intestine. This site is the location where the majority of digestion occurs and the absorption of nutrients takes place. The small intestine has three parts: the duodenum, the jejunum, and the ileum. Absorption primarily happens in the duodenum, which is the first section nutrients encounter when exiting the stomach, but some absorption occurs in the jejunum and ileum (Turley & Thompson, 2013). The small intestine is not a long, smooth tube. There are finger-like projections called villi and even smaller projections called microvilli that increase the surface area for greater absorption in the small intestine (Nelms, Sucher, Lacey, & Roth, 2011). In the large intestine, or colon, water absorption compacts the solid waste and the bacteria produce a significant amount of vitamin K (Turley & Thompson, 2013).
Digestive System

Figure-1: Human Digestive System. The human digestive system is the mechanism for digestion and absorption of nutrients, starting with ingestion and ending with excretion. Most vitamins and minerals are absorbed in the small intestine. The large intestine reabsorbs water, compacts solid waste, and the bacteria produce vitamin K. (“Health, Medicine, and Anatomy”, 2013)
In some instances, a disease may cause a person’s colon to become irreparable. The Barnett Continent Intestinal Reservoir (BCIR) is one method available to patients who have a diagnosis that requires a complete colectomy or those who are having difficulties with their current ileostomy. The BCIR is a pouch created from the ileum portion of the small intestine, about two feet of the small intestine is used (Figure 2). A valve is also created from intestinal tissue to stop leakage. The valve gives patients the option of when to empty the pouch. There is a feeling of fullness, but the problems of leakage in a typical ileostomy are removed. The duodenum and jejunum portions of the small intestine remain intact (“BCIR”, 2014).

Figure-2: BCIR. The small intestine is formed into a pouch to hold waste until a catheter is inserted to empty the pouch (“BCIR”, 2014)

The removal of the colon may change the way some nutrients are digested or absorbed by the body and may decrease the usefulness of others. Research has not been performed specifically on the BCIR in this area; however, other surgical procedures have been shown to alter nutrient metabolism. The first goal is to find out which nutrients are absorbed from the ileum and colon and thus may pose a nutritional issue for patients with the BCIR. This will be
done by researching nutrient metabolism and identifying likely nutritional issues. The second goal is to create a method of sharing this information with patients and present it in an easy to understand manner.

**Short Bowel and Proctocolectomy**

Patients with shortened bowel may have some of their colon intact. Parts of the small intestine may have been removed due to disease, and the healthy portions are then put back together (Buchman, 2006). Shortened bowel can be described by various missing pieces of the intestinal tract and thus can vary in length.

Proctocolectomy is a procedure much like the BCIR. The colon and rectum are removed, a pouch is constructed from the distal end of the ileum, and it is reconnected to a neo-rectum. The proctocolectomy only uses 1-1.3 feet of the small intestine to make the pouch, slightly less than the two feet used by the BCIR (Buckman & Heise, 2010). The total length of the small intestine is around twenty feet, depending on the height of the person (Yamada, 2009). The ileum is about 3/5 of the small intestine, around eight to twelve feet long (Buckman & Heise, 2010). There is a small portion of the small intestine being made into a pouch in both procedures, but the entire colon is removed in proctocolectomy.

Deficiencies in vitamins A, D, E, and K have been observed in patients with shortened bowel, along with folate, thiamin, and vitamin B₁₂ (Buchman, 2006). Patients having proctocolectomy have been found to be deficient in vitamin B₁₂, iron, vitamin E, sodium, potassium, magnesium, zinc, selenium, and chloride (Buckman & Heise, 2010). Both shortened bowel and proctocolectomy patients experience difficulties with waste management when
consuming recommended amounts of fiber. Each of these nutrients will need to be studied individually to decipher which ones might be a problem in the BCIR patient.

**Fat-soluble Vitamins**

Vitamins A, D, E, and K are fat-soluble vitamins essential for humans. Fat-soluble vitamins are absorbed into the lymph system before they enter the bloodstream, along with other lipids consumed. Lipids and fat-soluble vitamins are absorbed into the cells of the intestinal villi in the small intestine, where they are packaged into chylomicron lipoproteins to increase water solubility (Turley & Thompson, 2013). Fat-soluble vitamins are insoluble in water due to being nonpolar. Because blood is mostly water, fat-soluble vitamins must travel through the lymphatic system. Water molecules are polar and are attracted to each other by strong intermolecular hydrogen bonds. There is not enough attraction between the polar and nonpolar molecules to cause them to mix (Casiday & Frey, 2001). These fat-soluble vitamins have a large ratio of hydrocarbon chains and rings compared to polar hydroxyl or amine groups. This makes them nonpolar, as in Vitamin D, which only has one hydroxyl group (Figure 3). Before lipids can be taken up in the villi, they need to be emulsified by bile salts. This emulsification allows lipase enzymes to digest or break apart the lipids (Turley & Thompson, 2013). Bile salts are cholesterol derivatives and have both polar and non-polar regions. The bile salts and lipids create an ester bond, which increases the surface area and allows lipase enzymes to break down the lipids into glycerol and fatty acids before traveling across the plasma membrane. Once across the membrane, glycerol and fatty acids form triglycerides once again and are packaged, with proteins, as a lipoprotein transport particle, known as a chylomicron. They are then delivered to different organs in the body for use (Berg, Tymoczko, & Stryer, 2012).
Vitamin A

Vitamin A plays a role in vision, growth, and the immune system (Turley & Thompson, 2013). Vitamin A deficiencies can occur in patients with impaired absorption or chronic diarrhea (Kroner, 2011). Malabsorption of vitamin A is not often found to be a problem in proctocolectomy patients because fat absorption occurs largely before reaching the distal end of the ileum (Saway, Jaffe, Friedenberg, & Friedenberg, 2012). The majority of fat is absorbed at or before chyme reaches the first three to five feet of the jejunum, thus never reaching the ileum (Buchman, 2006).

There are several different forms of vitamin A. Carotenoids are a large group of compounds which give foods their red, orange, or yellow color. Carotenoids that are essential to animals have a β-bond along with three methyl groups in a terminal ring structure. This is connected to a chain of at least ten unsaturated carbons (Yamada, 2009). Beta-carotene is an important carotenoid. It is a precursor to preformed vitamin A, or retinoids (Gropper & Smith, 2013). Carotenoids are cleaved to form retinal, which can then form retinol or retinoic acid. Retinol can bind with fatty acids to form retinyl esters (Yamada, 2009). Figure 4 shows the chemical structures of beta-carotene (a), retinol (b), and retinal (c). One beta-carotene molecule
can form two retinal, or eventually retinol molecules. Carotenoids and retinoids can be found in food.

In patients with shortened bowel, bile salts, such as Cholestyramine, are not reabsorbed as readily, which can cause fat malabsorption. Some fat absorption does occur in the ileum. Bile salt supplementation can help in these cases. However, patients with more than three feet of the ileum removed should not supplement bile salts because excess fat will be excreted (Buchman, 2006). Proctocolectomy patients did not have an increased risk of vitamin A deficiency.

A patient with a BCIR may have a vitamin A deficiency caused by malabsorption. The majority of fat is digested and absorbed before reaching the ileum and colon. However, fat malabsorption can occur in patients having more than 1.9 feet of their ileum removed (Nightingale & Woodward, 2006). It is also possible that conditions like chronic inflammation or a poorly functioning pouch may cause changes in bile salt absorption, which can lead to fat malabsorption. Vitamin A in BCIR patients should be monitored. A BCIR patient might ingest adequate amounts of vitamin A from the foods they eat, such as eggs, meat, and milk. The body can also synthesize vitamin A from beta-carotene. A diet rich in orange colored foods that contain an abundance of carotenoids (sweet potatoes and carrots) provide beta-carotene. The active forms of vitamin A, retinol and retinal, come from animal sources, while beta-carotene comes from plant sources (Turley & Thompson, 2013). Active forms of vitamin A can be toxic due to supplementing high levels, thus in these cases close monitoring is necessary (Memorial Sloan-Kettering, 2012). Deficiencies of zinc or iron may also increase the risk of vitamin A deficiency, which would be important in BCIR patients (Kroner, 2011). Zinc is involved in the process of converting retinol to retinal, and iron is a cofactor for the enzyme that converts beta-carotene to retinal (Gropper & Smith, 2013).
Figure-4: Forms of vitamin A. Beta-carotene (a) comes from plant sources, but is less bioavailable for use in the body. Retinol (b) and retinal (c) can be found in animal products and absorption in the body is higher. (Scholastic Learning Circle, 2011).

**Vitamin D**

Vitamin D (Figure 3) is important for bone formation because it regulates the balance of phosphorus and calcium in the blood (Turley & Thompson, 2013). There is also a strong correlation between low levels of vitamin D and hypertension, diabetes, cancer, and infection (Kroner, 2011). It has only been in the last ten years that the chemical monitoring of Vitamin D status has been done. Vitamin D, a fat-soluble vitamin, is subject to the same absorption mechanisms as vitamin A. However, most Vitamin D does not come from food. Vitamin D is found in fatty fish, some mushrooms, and fortified foods. Depending on the UVB exposure and skin tone, the majority of Vitamin D can be synthesized in the body from cholesterol beginning in the skin and provided that the liver and kidneys are normally functioning (Turley & Thompson, 2013). People in areas of the world far from the equator, or those who avoid the sun are in danger of vitamin D deficiency.
Vitamin D is also known as calciferol and is a cholesterol derivative. Cholesterol has four intact rings in its chemical structure, while vitamin D has one ring that is broken open (Figure 3). There are two forms of vitamin D: ergocalciferol (D2) and cholecalciferol (D3). They are derived from ergosterol and cholesterol, respectively. The two forms have different side chains, but their functions in the body and general metabolism are similar (Gropper & Smith, 2013). The D3 form is needed in higher amounts in the body, this is the form that should be supplemented if needed (Yamada, 2009).

Patients with short bowel, specifically involving the ileum, may have an increased risk for vitamin D deficiency. Liver circulation may be disrupted in these patients, which can cause a disruption of vitamin D synthesis (Buchman, 2006). Similar malabsorption problems can occur from food forms of vitamin D as with vitamin A. Bile salts may not be reabsorbed properly, which can cause fat malabsorption.

Proctocolectomy patients also demonstrated an increased risk for vitamin D deficiency. In a study done on 157 proctocolectomy patients, 69.4 % had a vitamin D3 deficiency. This is much higher than the deficiency level found in the general population by the CDC, where 31% of non-Hispanic Black Americans had vitamin D deficiency, 12% for Mexican Americans and 3% for non-Hispanic whites (“CDCHome”, 2012). Vitamin D has an anti-inflammatory role in the body, and inflammation in the small intestine leads to malabsorption. It is a cyclical path in regards to vitamin D and intestinal health (Khanna, Wu, & Shen, 2013). Vitamin D is rapidly absorbed in the proximal small intestine, but the largest amount is absorbed in the ileum, which plays a large role in Vitamin D deficiency in proctocolectomy patients (Gropper & Smith, 2013).

Patients with the BCIR might be at risk of vitamin D deficiency due to the possible malabsorption of vitamin D from food, as well as a disruption in the endogenous synthesis of
vitamin D. They would also have even greater risk of increased malabsorption since the most vitamin D is absorbed in the ileum. BCIR patients would most likely benefit from vitamin D supplementation, specifically D₃. However, vitamin D levels in the body should be monitored (Kroner, 2011). High dose supplements may be needed when a deficiency is first detected, but a lower dosage should be maintained for long term use. Vitamin D toxicity can cause hypercalcemia. BCIR patients may increase their intake of vitamin D by eating fortified foods, such as cereal or orange juice. Vitamin D occurs naturally in some foods as well. Liver, eggs, and fatty fish contain vitamin D, as well as shiitake mushrooms (Gropper & Smith, 2013).

**Vitamin E**

Vitamin E (Figure 5) plays its nutritional role as an antioxidant primarily protecting the membranes of red blood cells from oxidation. Its ability to donate an electron to a radical or reactive oxygen species, which are damaging, electron deficient molecules, reduces the reactivity, or damaging potential, to the body that would otherwise cause disease. Vitamin E, and other antioxidants, richly provided by fruits and vegetables, have been associated with promoting health (Turley & Thompson, 2013). Antioxidants help prevent heart disease, certain cancers, and Alzheimer’s disease (Kroner, 2011).

Vitamin E includes eight compounds, called vitamers, which are divided into two groups, tocopherols and trienols. The tocopherols have 16 carbons in a saturated side chain (Figure 5), while trienols have unsaturated chains. All of these vitamers found in food have an RRR stereochemistry configuration. Synthetic forms of vitamin E may use stereoisomers of these vitamers and are not as biologically active as the RRR form. The form of the vitamin used should be listed on the nutrition label (Gropper & Smith, 2013).
Vitamin E is a fat-soluble vitamin, so there is the possibility of malabsorption in the BCIR patient. Vitamin E deficiency is generally rare, except in premature babies and people with fat absorption issues (Kroner, 2011). Even if a person is low in vitamin E, the deficiency level is not well defined. Toxicity can occur but only with very high doses of supplements. Vitamin E can be found in many plant foods, such as vegetable oils, nuts, seeds, and leafy vegetables (Turley & Thompson, 2013). BCIR patients who have fat malabsorption problem would most likely benefit from vitamin E supplementation.

**Vitamin K**

Vitamin K (Figure 6) is important in bone health and blood clotting (Kroner, 2011). In blood clotting, vitamin K is part of an enzyme cascade and is involved in synthesizing thrombin from prothrombin. Medications that make blood clotting times longer, or make the blood thinner, are vitamin K antagonists (Berg, Tymoczko, & Stryer, 2012). Vitamin K is present in some foods, but a large portion is made by bacteria in the colon (Buchman, 2006). Eubacterium and Fusobacterium are some of the bacteria that synthesize Vitamin K in the large intestine (Canny & McCormick, 2008).
Vitamin K has two naturally occurring forms. Phylloquinone (K₁) and menaquinone (K₂) differ in that menaquinone has an unsaturated bond in the phytol group coming off the ring structure. Phylloquinone is ingested from plant foods. Menaquinones are mainly synthesized by bacteria in the intestinal flora (Gropper & Smith, 2013).

Vitamin K is unlike the other fat-soluble vitamins in that it is not stored in the body in large amounts. Newborns and people with fat absorption problems are at risk for vitamin K deficiency. Patients with shortened bowel might have vitamin K deficiency due to fat malabsorption. Patients having proctocolectomy might have vitamin K deficiency due to fat malabsorption or the lack of normal Vitamin K sources due to the lack of the colon (Buchman, 2006).

Patients with a BCIR may be at risk of vitamin K deficiency. They lack a colon, which is where much of the vitamin K₂ is synthesized for use in the body. They also might have some fat malabsorption, which would contribute to vitamin K₁ deficiency. Vitamin K₁ comes from leafy, green vegetables in the greatest amounts (Turley & Thompson, 2013). Vitamin K can be supplemented without fear of toxicity, but patients with blood clotting disorders may not see an improvement. Patients should talk to a healthcare provider about a safe dose of vitamin K, because it interacts with many different medications (Kroner, 2011). Of the fat-soluble vitamins,
vitamin K has the greatest risk of deficiency in the BCIR patient since it is made by bacteria in the large intestine.

**Water-soluble Vitamins**

Vitamins that are soluble in water are absorbed in the small intestine, along with water, through the microvilli and travel through the blood (Turley & Thompson, 2013). Water is a polar molecule and is attracted to other polar molecules, such as water-soluble vitamins. Water molecules are attracted to each other by hydrogen bonds. Since water-soluble vitamins also have the ability to form hydrogen bonds, they are able to break the intermolecular forces between molecules of water and form attractions of their own. This allows them to travel through the blood freely (Casiday & Frey, 2001). Unlike fat-soluble vitamins, water-soluble vitamins are not stored for long periods of time in the body, except for vitamin B₁₂. Therefore, they must be replaced frequently. Withholding the intake, or a chronic inadequate intake, of most water-soluble vitamins causes deficiency to occur more rapidly.

**Thiamin**

Thiamin, or vitamin B₁, is a cofactor for the enzyme thiamin pyrophosphate that is involved in glycolysis, or energy metabolism. It is used to help metabolize carbohydrates and some amino acids. It also functions in appetite and the nervous system (Turley & Thompson, 2013). Like vitamin K, thiamin may be one of the vitamins synthesized by bacteria in the large intestine (Saway & al, 2012). Thiamin is synthesized by adding sulfide to the carboxyl end of a protein called ThiS.
Proctocolectomy patients showed no signs of thiamin deficiency from malabsorption. Thiamin deficiency has been seen in patients with shortened bowel, but only in those who had parts of the jejunum removed. Thiamin is mostly absorbed in the proximal jejunum, so BCIR patients would not be expected to have a thiamin deficiency (Buchman, 2006). Thiamin can be obtained through consumption of pork, whole grains, and enriched grain products (Turley & Thompson, 2013). BCIR patients should not have a problem absorbing enough thiamin from food consumption.

**Folate**

Folic acid play its primary role as a methylating agent in red blood cell formation. It also helps to maintain normal levels of homocysteine in the blood. Homocysteine is a damaging amino acid. Folic acid is a cofactor to homocysteine transmethylase which catabolizes homocysteine to either cysteine or methionine, which helps to prevent heart disease. Folate deficiency is most commonly caused by inadequate intake, but can occur due to malabsorption. Folate is the term used to describe the vitamin in its reduced form when it is found naturally in food and in the body tissues. Folic acid is used when the vitamin is found in supplements and fortified foods in its oxidized state. In foods that contain natural occurring folate, the vitamin must be digested into its monoglutamate form by carboxypeptidase. Folic acid is already in the monoglutamate form and does not need to undergo digestion (Gropper & Smith, 2013). Having a folate deficiency can result in anemia. It is very important to get enough folate during pregnancy (Kroner, 2011).

In patients with shortened bowel, a deficiency in folate was found in those having the proximal end of the jejunum removed, since most folate digestion occurs in the jejunum (Buchman, 2006). There was no deficiency found in proctocolectomy patients due to
malabsorption from surgery. It cannot be said, therefore, that BCIR patients have a likelihood of developing a deficiency in folate. Folate can be found in green vegetables, legumes, and some fruit juices. Folic acid is found in fortified foods (Turley & Thompson, 2013). BCIR patients should not have a problem obtaining enough folate in their diet.

**Vitamin B₁₂**

Vitamin B₁₂ is a large organic compound (Figure 7). Its primary role is as a methylating agent in the formation of red blood cells and it does play a role in the catabolism, or breaking down, of homocysteine in the blood, thus reducing the risk of heart disease and strokes. Folic acid, vitamin B₆, and vitamin B₁₂ are all required for homocysteine metabolism. Vitamin B₁₂ is also used to synthesize DNA, RNA, red blood cells, and nerve function. It is a cofactor in the energy production from amino acids and fatty acids (Turley & Thompson, 2013).

![Figure-7: Vitamin B₁₂ (Pharmacy and Drugs, 2012).](image)

Vitamin B₁₂ is produced by bacteria in the intestines of animals. Humans absorb B₁₂ from the large intestine which has been produced by the bacteria there. However, only a small portion
is absorbed and used in the body. Most vitamin $B_{12}$ in humans comes from food. Animals eat plants, which initiates bacterial growth and vitamin $B_{12}$ production in the intestines. $B_{12}$ is stored in significant amounts, mostly in the liver, of humans and animals. All animal foods provide dietary sources of vitamin $B_{12}$ (Scott, 1999).

The absorption of vitamin $B_{12}$ is a complex process. Since vitamin $B_{12}$ comes from animal products, it is bound to proteins when it enters the stomach. The proteins release vitamin $B_{12}$ when they come in contact with hydrochloric acid (Scott, 1999). Vitamin $B_{12}$ is then bound to intrinsic factor, which allows the vitamin to be absorbed. Vitamin $B_{12}$ then travels to the ileum where the absorption occurs (Turley & Thompson, 2013). Absorption of vitamin $B_{12}$ happens at specific protein receptor sites that exist only in the ileum (Nelms et al, 2011).

Patients with shortened bowel may have a vitamin $B_{12}$ deficiency if they have more than 1.9 feet of their ileum removed (Buchman, 2006). Deficiency of vitamin $B_{12}$ causes pernicious anemia which is deadly without medical intervention. Fatigue, shortness of breath, dizziness, and cold hands and feet are symptoms of pernicious anemia. This occurs because there are not enough red blood cells to carry oxygen through the body. These patients may require vitamin $B_{12}$ shots every one to three months (Memorial Sloan-Kettering, 2012).

Patient with proctocolectomy may also have vitamin $B_{12}$ deficiency. One reason being that part of the ileum has been turned into a pouch, though only 1-1.3 feet. It is possible that the pouch portion loses the absorption capability. It is also possible that bacterial overgrowth into the pouch may bind to $B_{12}$, which would decrease the concentration of $B_{12}$ available (Buckman & Heise, 2010). One study found that 25% of patients having proctocolectomy surgery had a subnormal vitamin $B_{12}$ level. This study measured vitamin $B_{12}$ levels at specific intervals after the surgery. The average time it took for $B_{12}$ deficiency to present itself was 2.9 years (Coull,
Tait, Anderson, McKee, & Finlay, 2006). Vitamin B_{12} is stored for long periods in the body, unlike other water-soluble vitamins. An amount can be stored for three to five years if dietary intake is abundant. When malabsorption occurs, the stores can be depleted more quickly due to the body using up the stored B_{12} and less being added to the stores at the same time (Scott, 1999).

The risk is high for BCIR patients to develop a vitamin B_{12} deficiency. Two feet of the ileum is used to form the pouch, more than the amount removed in proctocolectomy. It has been shown that removal of greater than 1.9 feet of the ileum results in deficiency in short bowel patients, and proctocolectomy patients also have deficiencies, possibly due to malabsorption within the pouch. BCIR patients may need to get inter-muscular injections of vitamin B_{12} in order to achieve B_{12} availability. A deficiency may not show up for a number of years after surgery, so having a physician check B_{12} levels periodically is important. Symptoms of a vitamin B_{12} deficiency are anemia, memory loss, vision problems, tingling in the hands and feet, and loss of appetite and should be noted by the patient (Turley & Thompson, 2013). A higher level of foods containing vitamin B_{12} should not be recommended in cases of B_{12} deficiency due to malabsorption. The patient would be consuming more animal products which would increase their saturated fat and cholesterol intake, and they may not absorb much more vitamin B_{12} from these foods.

**Minerals**

Minerals play many different roles in the body. They are structural components of cells, enzymes, and hormones, important for the regulation of pH, and are integral parts of vital proteins (Turley & Thompson, 2013). Minerals are grouped into two categories: major and trace. Major minerals are needed in amounts greater than 100 mg per day. Trace minerals are needed in
100 mg or less (Gropper & Smith, 2013). The mineral absorptions that might be in jeopardy in the BCIR patient are sodium, potassium, chloride, magnesium, iron, zinc, and selenium.

**Electrolytes**

Electrolytes are substances that either gain or lose an electron when put in a solution. Certain minerals are categorized as electrolytes because they play a role in balancing maintaining water homeostasis in the body (Gropper & Smith, 2013). The electrolytes that play a role in the body are sodium, potassium, and chloride. They function in balancing the fluid on the inside and outside of cells by osmotic pressure (Turley & Thompson, 2013). Electrolytes are important in overall body function and serve as regulators to keep all systems functioning. They are affected by the removal of the colon, because the colon absorbs a large amount of water and electrolytes for use in the body.

**Sodium**

Sodium functions as a major electrolyte in the extracellular fluid, including plasma, cerebrospinal fluid, and interstitial fluid, and also functions in pH balance. Hyponatremia, low blood sodium levels, results from insufficient intake of sodium and is associated with weakness and muscle cramping (Gropper & Smith, 2013). Much of the population consumes too much sodium in the form of salt in their diet, which can lead to increased blood pressure (Turley & Thompson, 2013).

The vast majority of sodium ingested into the body is absorbed. There are three pathways in which it is absorbed. The first pathway involves sodium and glucose being shuttled across cell membranes in the small intestine. In the second, sodium and chloride are absorbed in the small intestine and the proximal colon. The third pathway is in the colon and involves
sodium moving through a sodium channel based on concentration gradient. The human body absorbs much more sodium than it needs, so excess is filtered out in the kidneys and excreted in urine and sweat (Gropper & Smith, 2013).

Patients with short bowel may have sodium malabsorption in cases where the colon was removed but not in cases limited to small intestine portion removal (Nightingale & Woodward, 2006). Patients who were studied after proctocolectomy had a decreased loss of sodium in their urine (Buckman & Heise, 2010). This is due to more sodium being lost in excretion since it cannot be absorbed in the colon. Since it is not absorbed for use in the body, it is sent out as waste. The decreased sodium output in the urine is because more sodium is being used by the body.

Patients with a BCIR may be at risk for sodium deficiency due to the lack of a colon. They may need to use more sodium chloride, or table salt, on their food. Sodium can be absorbed readily in the jejunum, so an increase in the intake of sodium would increase absorption. It is not difficult to find foods with greater amounts of sodium, but patients should have their sodium levels checked by a physician. Excess sodium should not be consumed if it is not needed, since salt consumption can elevate blood pressure which leads to heart attack and stroke (Turley & Thompson, 2013). If the patient is consuming the typical American diet, excess sodium will not be needed.

**Chloride**

Chloride is an abundant anion electrolyte in the extracellular fluid. It affects fluid balance and helps to digest food through hydrochloric acid (Turley & Thompson, 2013). The most common dietary source of chloride is table salt, along with sodium. Salt is made up of about 60%
chloride and is found mainly in processed foods and meats. Chloride is usually referred to in conjunction with sodium as sodium chloride (Gropper & Smith, 2013).

Patients with short bowel do not have a problem with chloride deficiency unless the colon has been removed, because some absorption of fluids and electrolytes occurs in the colon (Nightingale & Woodward, 2006). Patients with proctocolectomy could have a chloride deficiency. Even though some fluids and electrolytes are absorbed in the jejunum, a deficiency can occur. One study found a decreased loss of chloride in the urine due to a decreased amount being absorbed for use in the body (Buckman & Heise, 2010).

BCIR patients may have a chloride deficiency due to the lack of a colon. Some chloride is absorbed in the jejunum, so an increase in the consumption of sodium chloride would likely fix this imbalance. A deficiency in chloride would likely accompany a deficiency in sodium. Patients should have their chloride levels checked if they are having muscle cramps and mental apathy (Turley & Thompson, 2013). Patients should not increase their salt intake without consulting a physician.

**Potassium**

Potassium is the major electrolyte in the intracellular fluid. It is important in muscle contraction and relaxation and in the normal function of a cell. It maintains fluid volume within the cell and decreases the rise in blood pressure caused by excess sodium by relaxing the smooth muscle around blood vessels. A potassium deficiency usually accompanies dehydration. Good food sources include fruits, vegetables, grains, and dairy. Using a salt substitute will also increase potassium (Turley & Thompson, 2013).
Patients with short bowel didn’t have potassium deficiencies unless diarrhea was a problem (Memorial Sloan-Kettering, 2012). Patients with proctocolectomy had no alterations in potassium balance (Buckman, 2010). Potassium deficiency is hypokalemia (low levels of serum potassium), which has an impact on the metabolism of carbohydrates following a meal. Severe hypokalemia can cause cardiac arrhythmias, glucose intolerance, and muscle weakness (Gropper & Smith, 2013).

Patients with a BCIR should not have a great risk of potassium deficiency. These patients do need to consume adequate amounts of water, so there may be a risk if dehydration becomes a problem. BCIR patients can consume plenty of potassium in their food. Potassium can be found in bananas, tomato sauce, and sweet potatoes in large amounts.

**Magnesium**

Magnesium performs many functions in the body. It plays a part in nerve and muscle functioning, the immune system, heart rhythm maintenance, bone structure, and is useful in controlling high blood pressure. Most of the magnesium in the body is stored in the bones (Kroner, 2011). The presence of vitamin D may increase the absorption of magnesium in the body. Most magnesium in the blood is found free as an Mg$^{2+}$ ion, but about a third is bound to albumin, a protein (Gropper & Smith, 2013).

Magnesium deficiency can occur when sections of the intestines have been removed, which are vital for magnesium absorption (Kroner, 2011). In patients with shortened bowel, magnesium deficiencies can occur because of reduced absorption. Magnesium can also chelate to unabsorbed fatty acids, which reduces absorption as well. Magnesium deficiency can also occur in patients with increased diarrhea (Nightingale & Woodward, 2006).
Patients with proctocolectomy can also experience magnesium deficiency. Patients with an ileostomy had low magnesium levels, due to poor absorption. Normal levels were restored after closure of the ileostomy (Buckman & Heise, 2010). It is possible for the kidneys to reabsorb magnesium, rather than excreting of it as waste, when the body is in need of more (Kroner, 2011).

BCIR patients should be aware of their magnesium levels, since they may be at risk for deficiency. Magnesium levels are not normally tested in routine deficiency blood tests so the patient will need to ask their doctor specifically. Both high and low levels of magnesium are dangerous, so patients should not supplement magnesium if they are not deficient (Kroner, 2011). Fatigue, vomiting, headache, and mental confusion are symptoms of hypomagnesemia. Symptoms occur within a short time after levels of magnesium in the blood dip too low (Gropper & Smith, 2013). Patients may be able to get sufficient magnesium from food. Magnesium can be found in many plant foods, including leafy vegetables, nuts, legumes, and whole grains.

**Iron**

Iron plays many roles in the body. It functions in hemoglobin and oxygen transport through the body (Kroner, 2011). It is also a component of some enzymes and proteins (Turley & Thompson, 2013). Iron deficiency can result in microcytic hypochromic anemia, which decreases immunity and causes fatigue (Kroner, 2011).

Iron is found in two forms in food, heme and nonheme. Heme iron (Figure 8) is bound in a porphyrin ring in hemoglobin and myoglobin. Heme iron is found in animal food sources and is freed from the ring structure by proteases in the stomach and small intestine, then readily absorbed into the body. Nonheme iron is bound to other components of food and is found mostly
in plants, but is also in dairy in small amounts. Nonheme iron is released by hydrochloric acid and proteases in the stomach as $\text{Fe}^{3+}$, or ferric iron. Some ferric iron is reduced to the ferrous form, $\text{Fe}^{2+}$, which is more readily absorbed. Vitamin C and other acids can form a chelate with ferric iron to make it available for absorption (Gropper & Smith, 2013).

Figure-8: Heme iron (Boudreaux, 2014).

Specific research and recommendations were not found regarding iron and short bowel, but iron deficiency can be a problem in proctocolectomy patients. Patients with an internal pouch that needs to be emptied in order to excrete waste lose blood in this process. Other factors may also contribute, such as decreased absorption and increased need (Buckman & Heise, 2010). Since short bowel patients do not have a specific absorption problem with iron, it can be assumed that blood loss is the main cause of iron deficiency in proctocolectomy patients.

BCIR patients are at risk for iron deficiency and anemia. These patients lose blood in the process of emptying the pouch just as proctocolectomy patients do. BCIR patients should be checked for iron deficiency periodically, especially if they are exhibiting symptoms of anemia. These patients may need to take an iron supplement, but should check with a doctor first as iron toxicity is also a possibility. It may be possible to get enough iron from food, however foods that contain the readily absorbed form of iron may also be high in saturated fat. Heme iron is more
readily absorbed and is found in organ and muscle meats, oysters, and clams. Non-heme iron, which is poorly absorbed, can be found in soybeans, spinach, and pumpkin seeds. Iron from non-heme sources can be absorbed more readily by consuming foods rich in vitamin C, in conjunction with non-heme food (Turley & Thompson, 2013).

**Zinc**

Zinc is vital in growth and development, functions in many enzymes, is needed for protein metabolism, and is required in the insulin synthesis process (Turley & Thompson, 2013). Zinc also plays a major role in immune function and DNA synthesis. Zinc is not stored in the body, so it must be consumed and replenished daily (Kroner, 2011).

Patients with short bowel may develop a zinc deficiency if they experience diarrhea frequently. There is not enough time for adequate absorption of the mineral if transit time is too short (Buchman, 2006). Proctocolectomy patients experienced zinc deficiency in very few cases. Zinc is absorbed in the small intestine. The pouch does not decrease transit time of nutrients in most cases. It is possible in the cases where zinc deficiency was exhibited that patients had frequent diarrhea (Buckman & Heise, 2010).

BCIR patients should not have an increased risk of zinc deficiency unless they are having frequent diarrhea. Patients in these circumstances should notify their doctor. BCIR patients do not normally have decreased transit time of nutrients, and zinc should be absorbed effectively in the small intestine. Patients can decrease their likelihood of zinc deficiency by eating foods containing zinc each day. Whole grains, fortified cereals, shellfish, and meats provide good sources of zinc (Turley & Thompson, 2013).
Selenium

Selenium is a structural component of many proteins that function as an antioxidants and have been associated with a lower risk of many diseases. These proteins protects against cancer and helps fight chronic illnesses. Selenium deficiency can occur in patients who cannot absorb enough, but more often occurs in certain areas of the world where selenium content in the soil is low (Kroner, 2011). Selenium deficiency can be displayed with symptoms of poor growth, muscle pain and weakness, and loss of hair and skin pigment. It is also linked to diseases that occur in certain parts of the world (Gropper & Smith, 2013).

Selenium deficiency can be a problem in short bowel patients who experience frequent diarrhea. Like zinc, selenium cannot be absorbed properly with low transit times of nutrients (Buchman, 2006). Patients with proctocolectomy do not generally have an increased risk for selenium deficiency (Buckman & Heise, 2010).

BCIR patients should not have an increased risk of selenium deficiency unless they live in an area of the world where selenium is not found in the soil or they have frequent diarrhea. Adequate selenium is easily consumed in the diet. Grains, dairy, fruits, vegetables, nuts and meats all contain selenium because it comes from the soil (Turley & Thompson, 2013). Selenium should not be supplemented in areas of the world where selenium content is adequate due to adverse effects (Rayman, 2012).

Fiber

Dietary fibers are non-digestible carbohydrates that are non-caloric. They nourish the human body through fermentation in the intestines. In the large intestine, these fermented molecules make immune function enhancers and facilitate the uptake of some minerals
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(Paeschke & Aimutis, 2011). Fibers are made up of polyglucose units, much like starch, but are connected by beta bonds. The human body does not have the enzyme needed to break these beta bonds, so fiber is not digested (Berg, Tymoczko, & Stryer, 2012).

An intake of adequate fiber exhibits many health benefits in the human body. Fiber adds bulk to the diet which decreases the caloric density of food. It also works as a stool softener and decreases transit time. It improves the tone of the muscles in the gastrointestinal tract and can bind to fat and cholesterol, decreasing the risk of heart disease. Fiber also increases gastric emptying time, causing a feeling of fullness after meals to last longer. If a person intakes too much fiber they can experience gas and bloating, frequent bowel movements, and binding of certain minerals. Fiber supplements used improperly have caused intestinal blockage (Turley & Thompson, 2013).

There are two types of fiber. Soluble fiber dissolves in water to form a gel and is found in fruits, vegetables, and legumes. Soluble fiber helps slow digestion. Insoluble fiber doesn’t soften in water, so it stays intact through the digestive tract. It can be found in whole grains and the peeling of fruits and vegetables. Insoluble fiber decreases transit time (Turley & Thompson, 2013).

In patients with short bowel, soluble fiber is more easily tolerated than insoluble fiber. The insoluble fiber can’t be broken down by the body and makes the stool more bulky. It also decreases transit time, which can cause mineral deficiencies in short bowel patients (Memorial Sloan-Kettering, 2012). In patients with short bowel, some extra carbohydrates may enter the colon since the small intestine has been made smaller. The decreased surface area of the small intestine may cause some digestible carbohydrate to enter the colon. These starches and soluble fiber are fermented into short chain fatty acids (SCFAs). This allows for less loss of energy
through the stool since undigested starches are being used in the colon. SCFAs can stimulate water and sodium absorption in the colon, which is one reason short bowel patients have less electrolyte deficiency (Buchman, 2006).

Patients having proctocolectomy reported intolerances to certain high fiber foods. Ileostomy patients are advised to remove the skin and seeds from fruits and vegetables to avoid obstruction. High fiber foods can cause an obstruction since fiber is not digested by the human body. This can happen more easily in patients without a colon since soluble fiber doesn’t have the chance to form a gel while in the colon. These fibers are not given the opportunity to be fermented and boost the immune function since there is no colon. High fiber foods increase stool output and cause excess gas (Buckman & Heise, 2010).

BCIR patients are very similar to proctocolectomy patients regarding the way their digestive tract works. They must also be careful of high fiber diets. BCIR patients may need to remove the skins from fruits, cook vegetables to soften them, chew their food well, and avoid foods that don’t break down in the body, such as mushrooms.

In some patients with intestinal diseases a low residue diet is recommended. In this type of diet, the goal is to eat less than 10-15 grams of fiber each day and avoid lactase. Patients on this diet are advised to eat refined grains rather than whole grains. There are limited vegetables they may consume raw. They should cook most vegetables very well. They should drink fruit juices and stick to a list of easy to digest raw fruits. They should avoid whole nuts and seeds (Dugdale, 2012).

Patients with a BCIR will need to experiment with different foods in order to judge which foods cause problems in their body. They may need to eat a low fiber diet, but should eat as
much as can be tolerated since high fiber foods are more nutritious than low fiber foods, specifically in grains. Many of the vitamins and minerals that can result in deficiency with BCIR patients are found in foods high in fiber as well. Some of the benefits of fiber do not apply to a patient with a BCIR. The BCIR patient does not get a stool softening effect from fiber. The opposite is actually true as too much fiber can cause constipation (“BCIR”, 2014). Fiber might improve the tone of muscles in the small intestine, but that benefit refers more fully to the colon. The patient does not benefit from the fermentation of fiber in the colon, which improves the immune system (Paeschke & Aimutis, 2011).

The BCIR patients still benefits from fiber in that it adds bulk to their diet and decreases the caloric density of meals. It also increases gastric emptying time, causing the patient to feel full longer. In these ways, fiber can be a benefit to the BCIR patient in losing weight or maintaining weight. There are specific fibers that also have a benefit BCIR patients can experience. Pectins and guar gum can increase the thickness of the mucous layer in the stomach, which protects against stomach ulcers. Soluble fibers may also be of greater importance to BCIR patients. Soluble fibers delay glucose uptake, which takes place in the small intestine. They also impede the absorption of lipids, which is beneficial the prevention of heart disease (Paeschke & Aimutis, 2011). Consuming adequate amounts of fiber can reduce the risk of coronary heart disease, stroke, peripheral vascular disease, and hypertension (Cho & Almeida, 2012).

**Informing the Patient**

It is important for BCIR patients to be aware of the deficiencies that are possible after surgery. Some of these deficiencies, such as vitamin B₁₂, may not present themselves for a number of years, but if patients are aware of the possibility they may recognize the signs when deficiency occurs. The BCIR surgery is performed in a small number of hospitals in the United
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States, so patients may need to educate their local physicians on the procedure and possible nutrient deficiencies. By doing this, patients may take an active role in their health and wellness and prevent deficiencies from ever occurring.

A brochure has been created to inform patients of the research findings in this paper (Appendix A). Written Health Information (WHI) is used to inform patients about diseases or conditions and educate them on procedures, therapy, and give other instructions (Luk & Aslani, 2011). When writing health information for patients it is important to remember that patients may not understand complex medical jargon or terms common in the medical community. It is best to keep the language plain and easy to understand (“Medline Plus”, 2013). It is important to think of readability, presentation, quality, and health literacy (Luk & Aslani, 2011). While creating the attached patient education brochure, these areas were taken into account.

It is important to know your audience when writing an educational brochure (“Medline Plus”, 2013). The attached brochure has been written with the BCIR patient in mind. This is not an information brochure on the BCIR procedure. It is intended for those who have already had the procedure or are planning to have the procedure in the near future. The brochure does not give information on the BCIR, but does inform patients of how the BCIR changes the digestion and absorption of nutrients.

Along with making the brochure easy to understand, it is important to include interesting images. An educational brochure was created about oral health, and patient focus groups reported that images in the brochure were very helpful. It was important that the images were large enough and placed so the text was broken up (Morgaine, Carter, Meldrum, & Cullinan, 2014). The images included in the attached brochure (Appendix A) each serve a purpose, whether it be educational or aesthetic.
The brochure has been broken up into sections. There is a section to inform patients which nutrients are at a high risk of deficiency, which nutrients are at moderate risk, and a section on fiber. There is also a section telling patients what they need to do. It is important when writing a medical brochure to give the patient a plan of action (“Medline Plus”, 2013).

The brochure (Appendix A) has been created in a tri-fold pattern. It is easily displayed and allows for sections to be broken up by the design. The design also makes it small enough that a patient could fit the brochure in a pocket or purse. They might keep it nearby for further reference. The objective of this brochure is to inform patients of nutrient absorptions that may change with a BCIR. The outcome desired is that patients will take an active role in their health by consulting their physician, eating a balanced diet, and being aware of what foods contain these nutrients.

Conclusion

Patients with a BCIR have a high risk of developing iron and vitamin B₁₂ deficiencies. These nutrients should be monitored closely by a physician, who should then recommend correct supplement dosages. It may be helpful for the patient to see a dietician as well. Patients are also at an increased risk of deficiencies in vitamins A, D, E, and K, sodium, chloride, and magnesium. These nutritional statuses should also be monitored by a doctor. Some of these nutrient deficiencies may be prevented through the consumption of food sources containing high nutrient values. Nutrients that BCIR patients do not have an increased risk for deficiency due to their medical procedure include thiamin, folate, potassium, zinc, and selenium. Patients should get adequate amounts of these nutrients through normal consumption of food.
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Less fiber may be needed in the BCIR patient’s diet, however the patient should eat amounts and types of fiber that are well tolerated by the body. Fiber loses some of its benefits in a BCIR patient due to loss of the colon, but other benefits remain intact. BCIR patients should consume more soluble rather than insoluble fiber types, while also consuming foods that contain the needed vitamins and minerals in which they are at risk for deficiency.

The diet of a BCIR patient can be a balancing act. Each patient and how his/her body functions have variations. The gastrointestinal tract can adapt to protect against nutrient loss in some cases. The role of one section of the small intestine might adapt to take on the role of another area based on the need of the body (Nelms et al, 2011). With the included brochure (Appendix A), BCIR patients can be made aware of possible deficiencies so they can monitor their own health and wellness. This will help to empower patients to recognize abnormalities and take the appropriate action if they occur.

The most important thing for BCIR patients to understand from this research is to consume a balanced diet. If these patients consume plenty of fruits, vegetables, low-fat dairy, lean or low-fat protein, and fortified grains, such as cereals, they can prevent many of these deficiencies from ever occurring. The typical American diet does not contain a lot of these foods, so BCIR patients must be more proactive and educated about their health. Also, by becoming educated about these deficiencies, they can take a proactive role in their medical care and inform their physician about the possibility of deficiencies.
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