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Quantitative Analysis of Potassium Concentrations in Hair of Breast Cancer Patients Using Atomic Absorption Spectrometry (AAS)

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Abstract—Breast cancer, a leading cause of cancer-related mortality, is associated with genetic mutations influenced by endogenous factors, such as DNA repair errors, and exogenous factors, including environmental pollutants and heavy metals. Potassium, an essential trace element, has emerged as a potential factor in cancer biology, although its role remains underexplored. This study aims to evaluate potassium concentrations in hair samples from breast cancer patients and healthy individuals using Atomic Absorption Spectrometry (AAS), a sensitive and cost-effective technique for trace element analysis. Hair, a non-invasive biological sample, was selected for its ability to reflect long-term exposure to environmental and metabolic changes. Results indicate significantly elevated potassium levels in breast cancer patients (mean: 226.65 ppm) compared to healthy controls (mean: 151.79 ppm), with levels ranging from 30.38 to 725.56 ppm in patients and 42.97 to 403.16 ppm in controls. These findings suggest a potential correlation between potassium accumulation and breast cancer, highlighting its possible role in cancer pathophysiology.

Keywords—Potassium content; AAS; breast cancer; hair analysis.

I. Introduction

Breast cancer is a type of cancer that begins when abnormal breast cells grow uncontrollably, dividing more rapidly than healthy cells and forming lumps or tumors. This abnormal cell growth is primarily caused by mutations in the genes that regulate cell function, particularly damage to Deoxyribonucleic Acid (DNA). These mutations can be triggered by both endogenous and exogenous factors. Endogenous factors, which account for 10-15% of gene mutations, include errors during cell division or failure in DNA repair mechanisms. In contrast, exogenous factors, including environmental exposures such as viruses, persistent infections, air pollution, obesity, radiation, and harmful chemicals in food, water, and air, are responsible for the majority (80-85%) of gene mutations (Meister & Morgan, 2000; Sainsbury, 2000; Enger, 2005). Understanding the role of these factors is crucial to comprehending how breast cancer develops and progresses.

In the context of cancer research, the measurement of heavy metal levels in the body is commonly conducted through blood and urine samples. However, biological samples such as scalp hair and nails are increasingly being used for this purpose. Hair, as a biological sample, offers several advantages over blood and urine, particularly for analyzing long-term exposure to environmental toxins. Hair grows from matrix cells, where elements from the blood are incorporated in a stable manner. Once formed, hair is no longer involved in the body's internal metabolism, making it an ideal medium for reflecting cumulative exposure to elements at the time of hair formation. As a result, hair analysis provides a non-invasive and relatively simple way to monitor heavy metal exposure over an extended period, which is particularly useful for cancer patients (Patty, 2011).

Research on the relationship between heavy metals and breast cancer has shed light on how these elements influence cancer development. For example, Liu Lin (2022) found significantly higher levels of copper, cadmium, and lead in breast cancer patients compared to healthy individuals, while zinc and manganese levels were notably lower. This suggests that heavy metals like cadmium, which mimic estrogenic effects, may contribute to breast cancer cell development. Copper, zinc, and manganese, on the other hand, play crucial roles in mediating the Reactive Oxygen Species (ROS) pathway, which is implicated in cancer progression. Similarly, studies by Tarhonska (2022) revealed that cadmium exposure increases the risk of breast cancer by inducing malignant transformation of normal breast cells and accumulating in the body over time.

While these findings are significant, the specific roles of individual heavy metals in breast cancer progression remain poorly understood. Potassium, an essential trace element, has emerged as a potential area of interest. It plays a critical role in maintaining cellular functions such as regulating fluid balance, nerve activity, and enzyme functions. Disruptions in potassium levels may indicate underlying metabolic imbalances commonly associated with cancer.

This study aims to explore potassium's potential as a biomarker for breast cancer by analyzing its levels in hair samples of breast cancer patients compared to healthy individuals. Hair is particularly suited for this analysis as it reflects cumulative exposure over time, making it an ideal medium for studying long-term metabolic changes. The findings could contribute to a deeper understanding of potassium's role in cancer biology and its utility in breast cancer diagnosis or monitoring.

Using Atomic Absorption Spectrometry (AAS), a sensitive technique for detecting trace elements, this study investigates potassium levels in hair samples. Previous studies, such as one conducted by Patty (2011), analyzed elemental content in hair samples from breast cancer patients using the X-Ray Fluorescence (XRF) method. Patty's study found significantly higher sulfur (S) and potassium (K) levels in the hair of breast cancer patients compared to a control group. This research builds on such findings by utilizing AAS to achieve precise measurements and identify any statistically significant differences in potassium concentrations between groups.

By focusing on potassium as a potential biomarker, this study seeks to enhance our understanding of its role in breast cancer progression and provide insights that could aid in early diagnosis or effective monitoring strategies.

II. MATERIAL AND METHODS

A. *Ethical Clearance and Research Permits*

Ethical clearance (EC) and research permits are essential for clinical research. The researcher has obtained ethical approval from Dr. Kariadi General Hospital, reference number 1637/EC /KEPK-RSDK/2023, approved on December 15, 2024. Research permission was also granted by Wongsonegoro Semarang Regional Hospital on February 8, 2024, under reference number B-000.9_166/II/2024.

B. *Sample Collection*

Following the approval of EC and research permits, hair samples were collected from adult women diagnosed with biopsy-confirmed breast cancer. Sample collection took place at the Oncology Unit of Dr. Kariadi General Hospital and the Integrated Cancer Unit of Wongsonegoro Regional Hospital, Semarang, from February to April 2024. Participants provided demographic details, including age, weight, height, chemotherapy history, hair dye usage, and kidney function.

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Inclusion Criteria:

- Women aged 18–60 years.
- Body Mass Index (BMI) within the normal range (18.5–29.9).
- Normal kidney function.

Exclusion Criteria:

- Recent hair dye usage (within the last five months).
- History of chemotherapy or radiotherapy.

Approximately 3 grams of hair was collected from participants who met the inclusion criteria and provided signed informed consent. Control samples were also collected from 10 healthy individuals with no cancer history who had performed breast self-examination (SADARI) between the 7th and 10th day after the first day of menstruation.

C. *Testing Heavy Metal Detection Methods on Hair*

Testing was conducted using three methods (XRF, AAS, and ICP-OES) on a single hair sample from a healthy individual to determine the effectiveness and accuracy of each technique. Potassium (K) levels detected were: XRF: 311.6 ppm, AAS: 47.01 ppm, ICP-OES: 43.97 ppm. The results from AAS and ICP-OES were closely aligned, indicating similar sensitivity, detection limits, and accuracy for both methods. However, XRF produced significantly higher (and inconsistent) results. The similarity between AAS and ICP-OES demonstrates their reliability, with AAS being the more cost-effective option. Therefore, the AAS method was chosen for the study to analyze potassium differences in hair samples from healthy individuals and breast cancer patients.

D. *Sample Preparation*

Hair samples were sterilized using acetone-soaked surgical scissors and stainless-steel spoons. The samples were then cut, sieved through a 100-mesh sieve, and stored in clip bags. A 1-gram sample was weighed and transported to the Chemistry Laboratory at UKSW Salatiga. Wet digestion was carried out in June-July 2024 using Nitric Acid (HNO_3), with the following steps:

- The sample was mixed with 2 mL of HNO_3 and heated to 180°C.
- After the solution cooled, it was filtered, diluted with deionized water to a final volume of 100 mL, and transferred to a sterilized glass bottle.

E. *Sample Shipping and AAS Testing*

Hair samples were shipped in two phases to the KST BRIN Laboratory in Bandung: the first shipment in June 2024, with results available in July, and the second in July 2024, with results in August. AAS calibration curves for each element were plotted, achieving an R^2 value of 0.99 to ensure accurate results.

III. RESULT AND DISCUSSION

A. *Pottasium Content in Healthy Hair*

Out of 18 healthy respondents, only 10 met the inclusion criteria (aged <60 years with BMI within the range of 18.5–29.9). The average age of the healthy respondents was 29.4 years, with the youngest being 22 years old and the oldest 48 years old. The results of the AAS analysis for these 10 healthy hair samples, meeting all inclusion criteria, are presented in **Table 1.**

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Table 1. Potassium Concentration in Healthy Hair Samples

Healthy Sample	Potassium (K) Concentration (ppm)	Healthy Sample	Potassium (K) Concentration (ppm)
H1	309.8	H6	168.67
H2	105.65	H7	137.56
H3	403.16	H8	137.56
H4	47.01	H9	42.97
H5	67.2	H10	98.31
Average			151.79
Maximum			403.16
\Minimum			42.97

The table shows the concentrations of Potassium in each of the healthy hair samples. The concentration of potassium (K) in the 10 healthy hair samples varied significantly, ranging from a minimum of 42.97 ppm to a maximum of 403.16 ppm. The average concentration of potassium across all samples was 151.79 ppm. This variation suggests that potassium levels in healthy hair can fluctuate considerably, but the average concentration provides a representative value for the sample set.

B. *Potassium Concentration Cancer Hair Samples*

During the period from February 13 to April 5, 2024, interviews were conducted with 100 breast cancer patients at Dr. Kariadi Central Hospital and Wongsonegoro Regional Hospital in Semarang. A total of 71 breast cancer patients were excluded due to the following reasons: 11 patients were obese, 5 patients had dyed their hair, 15 patients were over 60 years old, and 19 patients had previously undergone chemotherapy. Additionally, 12 patients declined to provide hair samples, and 9 patients' hair samples did not meet the minimum mass required for AAS testing.

As a result, only 29 hair samples from breast cancer patients met the inclusion criteria and were eligible for laboratory testing. The average age of the cancer respondents was 47.5 years, with the youngest being 20 years old and the oldest 60 years old. The AAS test results from 29 hair samples of breast cancer patients with BMI in the normal range (18.5–29.7), hereinafter referred to as the "breast cancer plus samples," are presented in **Table 2.**

Table 2. Potassium Concentration in Hair Samples from Breast Cancer Patients

Cancer Sample	Potassium (K) Concentration (ppm)	Cancer Sample	Potassium (K) Concentration (ppm)
C1	136,44	C15	170,91
C2	143,99	C16	259,86
C3	154,01	C19	215,92
C4	278,59	C20	130,99
C5	30,38	C21	154,80
C6	138,38	C22	700,30

C7	272,40	C23	208,30
C8	447,20	C24	182,70
C9	194,73	C25	179,03
C10	142,87	C26	141,69
C11	63,84	C27	92,17
C12	725,56	C28	234,63
C13	312,29	C29	244,76
C14	162,90		
Average			226,65
Maximum			725,56
Minimum			30,38

Out of the 29 samples, 2 samples (C17 and C18) were undetectable, resulting in an average potassium concentration across the remaining 27 samples of 226.65 ppm. The highest potassium concentration observed was 725.56 ppm in sample C12, while the lowest was 30.38 ppm in sample C5. The average potassium level in normal hair samples was 100.62 ppm. This indicates that the average potassium concentration in the hair of breast cancer patients is higher than that of healthy individuals.

A study by Diana Patty (2011) also reported elevated potassium levels in the hair of breast cancer patients, with concentrations of 3000 ± 5600 ppm when tested using the XRF method. This demonstrates a wide range of potassium levels among the "breast cancer plus" group, suggesting that individual factors, such as differences in metabolism or treatment effects, may influence potassium content in the hair.

When comparing the potassium levels in these 27 cancer patients to the healthy controls, the results from Figure 1 showed that the potassium concentration in the breast cancer plus group was generally higher. This suggests that breast cancer patients, even with a normal BMI and age range, may experience higher potassium levels in their hair, which could be linked to the physiological changes caused by cancer or treatments. The potassium concentrations observed in this study might offer valuable insights into the metabolic alterations associated with cancer.

Based on the data above, 27 breast cancer hair samples show the accumulation of heavy metals, which is consistent with findings from the IAEA on trace element levels. Heavy metals, such as zinc, copper, potassium, and iron, are essential trace elements that play important roles in various cellular functions. However, their roles shift to become toxic when present in excessive amounts within cells (A. Romaniuk, 2017). While it remains unclear which specific heavy metals have the greatest impact on the development of breast cancer, the accumulation of these elements, particularly potassium, may be significant in understanding cancer's pathogenesis. Potassium, as a key element, could be involved in cellular dysfunction that promotes cancer development, though further research is needed to establish this link.

Breast cancer incidence is more prevalent in urbanized countries, which suggests that environmental factors, alongside other influences, significantly contribute to the initiation and progression of breast neoplasia. The rapid expansion of industrial activity leads to the contamination of soil, surface water, and food with heavy metal salts. In Ukraine, for instance, there has been an increase in the levels of iron, chromium, copper, nickel, lead, and zinc salts in the soil (Vashkulat, 2002). These contaminants may increase the exposure of individuals to toxic levels of metals, thus contributing to breast cancer development.

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The carcinogenic effects of heavy metals are mediated through mechanisms that disrupt DNA structure and suppress antioxidant protection (Bont DR, 2002) (Xi H, 2008). Heavy metals may also influence the expression of key prognostic receptors in breast cancer tissue, potentially altering tumor behavior and response to treatment (Traylor, 2008) (Lowndes, 2009).

Tumor tissue DNA exhibits altered methylation patterns that change with the accumulation of heavy metals, including potassium, in cancer cells. Through pathogenetic interactions, heavy metals stimulate the progression of breast cancer and reduce the efficacy of treatments. Studies have shown that breast tissue, whether influenced by tumor processes or not, can accumulate heavy metals, which in turn affect DNA fragmentation and the survival of tumor cells (Romaniuk, 2015). Thus, the role of trace elements, especially potassium, in breast cancer warrants closer examination to better understand its contribution to cancer development and progression.

Potassium (K) channels, particularly those like KCa3.1 (KCNN4), have been shown to play a role in the migration and proliferation of breast cancer cells, and their expression correlates with more aggressive forms of the disease, such as high-grade tumors with negative lymph nodes.

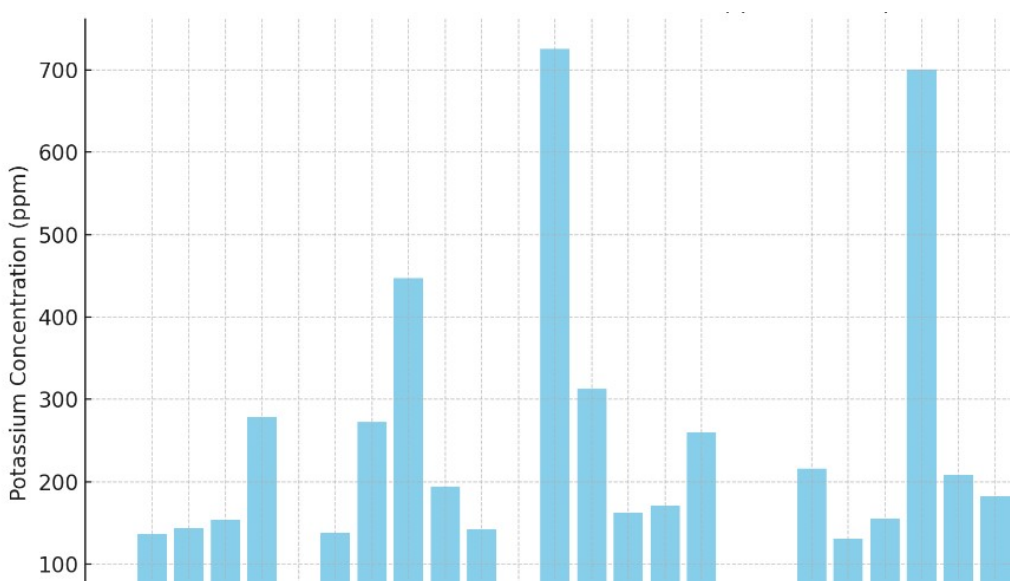

Fig 1. Potassium concentrations of breast cancer patients plus hair samples

Recent studies have explored how the expression of ion channel genes, including potassium channels, varies in breast cancer tissue. A signature of ion channel gene expression, referred to as "IC30," has been identified, with potassium channels among the most significantly altered. Moreover, the International Atomic Energy Agency (IAEA) supports ongoing research in this area, particularly related to breast cancer imaging and diagnostics, which may indirectly involve the study of heavy metals and trace elements like potassium in biological samples.

IV. CONCLUSION

Based on the data obtained from the study, the results for potassium (K) in hair samples are noteworthy. In healthy individuals, the average potassium content in hair was found to be 151.789 ppm, with a range of 42.97 to 403.16 ppm. In breast cancer patients, however, the average potassium content increased to 226.65 ppm, with values ranging from 30.38 to 725.56 ppm. This significant increase in potassium levels in the hair of cancer patients compared to healthy individuals suggests a potential correlation between potassium accumulation and the presence of breast cancer.

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Out of 27 breast cancer patient hair samples, potassium being notably elevated in comparison to healthy controls. This finding could indicate that potassium might play a role in the biological processes associated with cancer development, although the specific mechanism of its involvement remains to be fully understood.

Further research is needed to explore how potassium levels specifically influence the progression of breast cancer and whether these elevated levels could serve as a potential biomarker for early detection or as a therapeutic target.

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