Alpha-mangostin reduces cell viability in sorafenib-surviving cells by modulating multiple drug transporters in HepG2 hepatocellular carcinoma cells

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ARTICLE INFO

Received on: 10/12/2020
Accepted on: 20/03/2021
Available online: 05/06/2021

Key words:
Alpha-mangostin, sorafenib resistance, drug transporters, P-glycoprotein, OCT1.

ABSTRACT

A previous study showed that alpha-mangostin (AM) showed benefit when given to sorafenib (SOR)-surviving cells. However, the mechanism was not fully understood. The present study aimed to understand the effect of AM on SOR-surviving cells and its agent concerning drug transporters. SOR-surviving cells were treated with SOR 10 μM. Surviving cells were divided into four groups of treatment, namely, vehicle only dimethyl sulfoxide (DMSO), SOR 10 μM, AM 20 μM, or combination of SOR 10 μM-AM 20 μM. As controls, HepG2 naïve cells were treated with DMSO only or AM 20 μM. Cell viability was counted using trypan blue exclusion assay. Simultaneously, the mRNA expressions of P-glycoprotein (P-gp), ABCG2, MRP2, MRP3, OCT1, and OATP1B3 drug transporters were examined with quantitative reverse transcriptase-polymerase chain reaction. Decreased mRNA expression of P-gp was found in SOR-surviving cells treated with SOR. In contrast, AM alone or SOR's combination caused a significant increase in both efflux and influx transporters, no difference in fold increase of all transporters evaluated in AM versus SOR-AM combinations. Generally, AM treatment increased the mRNA expression of all the drug transporters.

INTRODUCTION

Hepatocellular carcinoma (HCC) is considered as the most serious complication of cirrhosis and chronic liver disease. HCC is the sixth most common cancer, being the fourth leading cause of cancer mortality worldwide in 2018. It also accounts for the fifth most common cancer in males and the female's ninth most common cancer. Previous findings showed a 35% increase in the mortality rate (Bray et al., 2018; Dasgupta et al., 2020).

The therapeutic advancements over the past several years have brought about rapid evolution to overcome HCC. Several approaches have been increasingly utilized to treat HCC, including hepatic resection, transplantation, radiofrequency ablation, chemoembolization, and systemic anticancer therapy (Grandhi et al., 2016; Ikeda et al., 2018).

Unfortunately, most HCC patients are diagnosed after the advanced stage since they do not show noticeable signs and symptoms early on (Bruix et al., 2016; Grandhi et al., 2016). In this scenario, multikinase inhibitors are the treatment of choice, with sorafenib (SOR) being the first-line treatment (Bouattour et al., 2019; Finn et al., 2018). Unfortunately, resistance to SOR develops rapidly about 6 months after treatment initiation (Bouattour et al., 2019; Cabrall et al., 2020).

There are plenty of mechanisms that have been suggested regarding SOR resistance. Drug transporters were reported to be involved in the development of SOR resistance. Several studies described the involvement of ABC transporters and OCT1 uptake transporters affecting the efficacy of SOR (Edginton et al., 2016; Geier et al., 2017; Louisa and Wardhani, 2019; Tang et al., 2020; Tomonari et al., 2016).

Some studies have investigated the benefit of combination therapy to prevent or reduce SOR resistance. Alpha-mangostin (AM), a naturally occurring xanthone isolated from the pericarp of Garcinia mangostana, was previously studied in HCC cells. The results suggested that AM exerts its antitumor effect...
by inducing apoptosis and cell cycle arrest (Chang et al., 2013; Wudtiwai et al., 2018). Moreover, AM has shown modulatory activity in several multidrug-resistance transporters (Dechwongya et al., 2017; Laksmiani, 2019; Wu et al., 2017a).

In a recent study, Adenina et al. (2020) reported that the addition of AM to SOR in HCC cells’ surviving SOR showed beneficial effect. However, the mechanism of how AM reduces cell viability in the previous system has not yet been elucidated. Consequently, the present study aimed to investigate the effect of AM in SOR-surviving HCC cells concerning several drug transporters’ expressions.

MATERIALS AND METHODS

Cells and cell culture

HCC cells, HepG2, were gifted by the Eijkman Institute for Molecular Biology. The cells were cultured as described previously (Louisa et al., 2016). Briefly, HepG2 cells were seeded in a culture dish for 48 hours until they reached the right confluence, divided into six treatment groups, as described in Figure 1. The first two groups that served as control were naïve HepG2 cells treated with vehicle only (DMSO) for 48 hours, followed by 24-hour treatment with DMSO or AM 20 mM. To select SOR-surviving cells, HepG2 was incubated with SOR 10 mM for 24 hours. Cells that survived 24-hour SOR 10 mM incubation were then considered SOR-surviving cells described by Adenina et al. (2020). Afterward, the medium was changed, and the cells were treated 24 hours with DMSO or SOR 10, AM 20 mM, or a combination of SOR 10 and AM 20 mM. Both AM and SOR were dissolved in DMSO at a final concentration of 0.01%. Then, the cells were counted using the trypan blue exclusion method and harvested.

Quantitative reverse transcriptase-polymerase chain reaction (qRT-PCR) of drug transporters

RNA was isolated from the harvested cells using Total RNA Mini Kit (Geneaid). RNA was then processed to cDNA using ReverTra Ace qPCR Master Mix with gDNA Remover (Toyobo). Analysis of P-glycoprotein (P-gp), ABCG2, MRP2, MRP3, OCT1, and OATP1B3 mRNA expressions was performed on qRT-PCR Light Cycler 480 (Roche) with Thunderbird SYBR qPCR Mix (Toyobo, Japan) using 100 ng of cDNA templates. The cycle threshold (Ct) was calculated automatically by using the software. The Ct data were then processed using the (Livak and Schmittgen, 2001) method to determine the normalized expression ratios of target genes. β-Actin was used as the housekeeping gene. Primers used in the present study were described in Table 1.

Data analysis

Results were presented in means ± SEM. Differences between groups were analyzed using the one-way analysis of variance test, followed by the post hoc Tukey method.

RESULTS

Cell viability

We observed a marked reduction in cell viability when SOR-surviving cells were treated with another dose of SOR or AM or SOR-AM combination, with the most potent effect being the combination group (Fig. 2). As for AM, treatment in naïve cells only resulted in a small cell viability reduction over control.

Drug efflux transporters

In HepG2 naïve cells, AM and SOR minimally affect the drug efflux transporters, while in SOR-surviving cells, treatment

Figure 1. The flow of experiments in the study.
with SOR increased the mRNA expressions of BCRP, MRP2, and MRP3 but not P-gp. SOR tends to decrease the mRNA expressions of P-gp. The treatment of AM and SOR-AM combination significantly increased all of drug efflux transporters evaluated (P-gp, BCRP, MRP2, and MRP3) (Fig. 3).

**Drug influx transporters**

Like drug efflux transporters, AM minimally affects drug influx transporters in HepG2 naïve cells, while SOR increased the expressions of OCT1 significantly. In SOR-surviving cells, all treatments (SOR, AM, and SOR-AM combination) increased OCT1 and OATP1B1 influx transporters, with AM treatment being the strongest. However, there were decreased expressions of OCT1 expressions in the SOR-AM combination when compared to AM alone.

**DISCUSSION**

The present study aimed to analyze the impact of AM on cell viability and its association with hepatic drug transporters mRNA expression in SOR-surviving human HCC HepG2 cell line.

Our study found that AM indeed modulated mRNA expression of six drug transporters that were examined in this study. This would then serve as an initial stepping stone, adding to a growing body of literature on AM’s beneficial pharmacological properties.

Additionally, a recent study has demonstrated the chemosensitizing effect of AM, leading to its use as adjunctive treatment to the available anticancer chemotherapeutic agent. Adenina et al. (2020) also reported in their study regarding the reduced cell viability in SOR-surviving cancer cells following AM treatment. Nevertheless, the mechanism remained not fully understood. As for anticancer agents through drug transporters modulation, only a few studies have explored AM’s impact on it (Chen and Duda, 2020; Ibrahim et al., 2016; Ovalle-Magallanes, Table 1. Primers used in the study.

| Genes | Primer | Sequence |
|-------|--------|----------|
| β-actin | Forward | 5′-GCTGGAAGTGGACAGGGA-3′ |
|       | Reverse | 5′-GGCATCGTGATGAACACT-3′ |
| P-gp   | Forward | 5′-TTACATTCAGTTTCAATTTTGTTG-3′ |
|       | Reverse | 5′-TCCTGTGCATTATAGCATGA-3′ |
| ABCG2  | Forward | 5′-TTCCAGAACAACCCGGGATAA-3′ |
|       | Reverse | 5′-ACAGAGGCTGGTGGCAAC-3′ |
| MRP2   | Forward | 5′-ACATTACCTTTCATCTGATGA-3′ |
|       | Reverse | 5′-TGATGGATGACCCCTGGCTA-3′ |
| MRP3   | Forward | 5′-TGATGGATGACCCCTGGCTA-3′ |
|       | Reverse | 5′-TGATGGATGACCCCTGGCTA-3′ |
| OCT1   | Forward | 5′-AACATCTGATAATCCATATGGCAGC-3′ |
|       | Reverse | 5′-AACATCTGATAATCCATATGGCAGC-3′ |

**Figure 2.** Percentage of cell viability over control after treatment of HepG2 cells with controls or HepG2 SOR-surviving cells treated with SOR or AM or combination of SOR-AM. Results are presented in mean ± SEM. *p < 0.05 versus DMSO-DMSO; †p < 0.05 versus DMSO-AM; ‡p < 0.05 versus Sor-DMSO. DMSO: DMSO 0.01%; AM = alpha-mangostin 20 mM; SOR = sorafenib 10 mM.

**Figure 3.** The mRNA expressions of drug efflux transporters after treatment of HepG2 cells with controls or HepG2 SOR-surviving cells treated with SOR or AM or combination of SOR-AM. (A) P-gp; (B) BCRP; (C) MRP2; (D) MRP3. Results are presented in mean ± SEM. *p < 0.05 versus DMSO-DMSO; †p < 0.05 versus DMSO-AM; ‡p < 0.05 versus Sor-DMSO. DMSO: DMSO 0.01%; AM = alpha-mangostin 20 mM; SOR = sorafenib 10 mM.
The present study revealed that AM interestingly influenced drug transporters mRNA expression.

In terms of drug efflux transporters, it can be observed that the mRNA expression of the P-gp transporter showed a twofold decrease in SOR-surviving cells when treated with another dose of SOR. Our finding is in agreement with the study conducted by Beretta et al. (2017) and Tang et al. (2020) which reported the multitarget properties of SOR, including ABC transporters. From the mentioned study, it can be inferred that SOR has substrate-like properties at low concentrations while revealing its function of inhibition at higher concentrations such as the one used in the present study, that is, 10 μM. SOR concentrations used in this study were based on the highest achievable clinical blood concentration, as confirmed by Haga et al. (2017).

The other transporters on the same category in the present study, namely, ABCG2/BCRP, MRp2, and MRp3, in contrast to P-gp showed increased expression in SOR-surviving cells when treated with additional SOR dose. The possible underlying reason was that SOR displayed wide variability in affecting the drug transporters (Beretta et al., 2017). Thus, this cellular context that scientists are currently trying to elucidate could heavily impact the drug transporters with unpredictable outcomes (Beretta et al., 2017).

Regarding the impact of AM on efflux transporters, alone or in combination with SOR, it generally showed increased mRNA expression ranging from about 2- to 5-fold higher than SOR-surviving cells. Our results indicated that the condition of inhibition at higher concentrations such as the one used in the present study, that is, 10 μM. AM = alphamangostin 20 mM; SOR = sorafenib 10 mM.

A meta-analysis by Burt et al. (2016) had managed to reveal the quantitative abundance of hepatic transporters in the Caucasian population. HepG2 cell lines were initially derived from a well-differentiated liver tumor of a 15-year-old Caucasian male (Dubbelpoer et al., 2019). Several interpretations can be made using meta-analysis data about the proportions of liver drug transporters. The protein abundance proportion of OATP1B3 and OCT1 is 31% and 12%, respectively (Shukla et al., 2016). The ratio of MRp2, P-gp, MRp3, and ABCG2 from that meta-analysis showed merely 2%, 2%, 1%, and 0.34%, respectively. The remaining ~51.66% proportion of transporters from the meta-analysis were not studied in the present study. Nevertheless, the trend still revealed more predominant influx transporters (~44%) compared to efflux transporters (~7.66%) (Shukla et al., 2016).

Recapitulating the number of folds of increased mRNA expression of AM treatment in SOR-surviving cells from the present study, the highest for efflux and influx transporters were MRp3 and OATP1B3 with 5.6-fold higher and 4.9-fold higher, respectively. At this point, it seemed that MRp3 showed more increase, which gave the impression of net efflux effect following the AM treatment. However, we could, fortunately, appreciate from the previous paragraph that OATP1B3 serves as the most abundant transporter (31%), while MRp3 is only 1% of the total abundance. To put it another way, although efflux transporters have a higher number of folds compared to the influx, it has a much smaller proportion compared to influx transporters, which are more superior in terms of the quantitative abundance. At this moment, the net influx effect would then be the predominant one to be observed. This calculation again obviously needed closer inspection since the meta-analysis was revealing data of protein abundance, while the present study was showing results of mRNA expression. However, Liu et al. (2016) suggested that despite the substantial contribution of posttranscriptional regulation that may occur, it may only minimally alter the abundance rank of the mRNA expression of the multidrug-resistance efflux transporters from producing the chemosensitizing effects as demonstrated in a study by Wu et al. (2017a), while another study reported a molecular docking analysis study using MCF-7 cells, which showed a relatively strong interaction between AM and P-gp as evidenced by the presence of three hydrogen bonds (Laksmiani, 2019).
protein in a cell. Therefore, the posttranscriptional impact did not seem to markedly affect the relative differences between proteins, which consequently supported the author's analysis of the present study (Liu et al., 2016). Aside from abundance, Beretta et al. (2017) research also suggested SOR inhibiting properties on many efflux transporters.

As for AM, it was confirmed by some studies to enhance the anticancer effect (Wu et al., 2017a, 2017b; Wuditiwai et al., 2018) which leads to the AM potential of exerting chemosensitizing effects by modulating drug transporter's expression. The findings in this study managed to provide a fair investigation by revisiting the roles of efflux transporters and appreciating the influx transporters in terms of their role in anticancer resistance.

In conclusion, our study confirms that AM did influence the mRNA expression of both efflux and influx drug transporters in a SOR-surviving HCC cell line (HepG2).

ACKNOWLEDGMENTS

The authors acknowledge the Indonesian Ministry of Research and Technology, National Research and Innovation Agency, for providing the Basic Research and Higher Education Excellence Grant 2020.

AUTHOR CONTRIBUTIONS

All authors made substantial contributions to conception and design, acquisition of data, or analysis and interpretation of data; took part in drafting the article or revising it critically for important intellectual content; agreed to submit to the current journal; gave final approval of the version to be published; and agree to be accountable for all aspects of the work. All the authors are eligible to be an author as per the international committee of medical journal editors (ICMJE) requirements/guidelines.

CONFLICTS OF INTEREST

The authors report no financial or any other conflicts of interest in this work.

ETHICAL APPROVALS

Not applicable.

PUBLISHER’S NOTE

This journal remains neutral with regard to jurisdictional claims in published institutional affiliation.

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How to cite this article:
Wangsaputra VK, Adenina S, Louisa M. Alpha-mangostin reduces cell viability in sorafenib-surviving cells by modulating multiple drug transporters in HepG2 hepatocellular carcinoma cells. J Appl Pharm Sci, 2021; 11(06):105–110.