Drug resistance is one of the primary obstacles in cancer chemotherapy. The causes of drug resistances are varied. The primary resistance attributed to genomic instability while alteration in membrane permeability of drug and inability to reach the target sites, drug inactivation by enzymes, mutation and altered expression of target proteins thereby affecting drug target interactions are some of the mechanism of acquired drug resistance. In addition to genetic changes there are epigenetic changes or non mutational mechanisms which occur quickly in response to environmental changes. Normal tissues never develop resistance to chemotherapy, because they possess intact genetic machinery. Drug resistance in addition to reducing clinical effectiveness, result in early termination of treatment, reduced relapse free interval and survival. There are various methods for overcoming these major disadvantages of cancer chemotherapy. Combination chemotherapy with clear understanding of the biochemical, molecular and pharmacokinetic mechanisms of interaction between the individual drugs in a given combination is one method. Optimal cancer drug scheduling is also a strategy for controlling resistance to therapy. Control avenues of drug administration and dose intensification provide better outcome. Despite various measures to overcome drug resistance, the problem especially multidrug resistance is still casting its shadow in successful chemotherapy. A better understanding of mechanism of drug resistance, its genetic and epigenetic links will open up new avenues in circumventing this fundamental problem and prolong the life expectancy of the patient. This article gives an overview of drug resistance encountered in cancer chemotherapy.

Keywords: Cancer, Chemotherapy, Cell cycle, Drug resistance
the proliferating normal tissues. The primary obstacles to the clinical efficacy of chemotherapy have been the toxicity to the normal tissues of the body and the development of cellular resistance to these chemotherapeutic agents. Drug resistances occur in most tumours treated with chemotherapy. Normal tissues never develop resistance to chemotherapy, because they possess intact genetic machinery. Sensitive cancer cells later develop resistance because of drug-induced mutations in their DNA. In the last decade, molecular techniques for analysis of the DNA of normal and neoplastic cells identified some of the critical mechanisms through which chemotherapy induces cell death. A new level of understanding of the molecular pathways through which chemotherapy works has opened up avenues for novel therapeutic approaches. Such strategies not only enhance the chemosensitivity of malignant cells to treatment, but also reduce toxicities and prevent the emergence of drug resistance.

**MECHANISM OF DRUG RESISTANCE**

One of the frequent problems encountered in cancer chemotherapy is drug resistance. Only tumour cells that are sensitive to the action of drugs are killed. There are several types of drug resistances which are broadly divided into primary or inherent and acquired. Various mechanisms are attributed to drug resistance. Alteration in membranes permeability causing inability to enter the target cells, increased drug efflux, inactivation by enzymes affect the concentration of drug within the cancer cells. Drug target interaction is prevented by mutation or altered expression of the target protein. Defects in apoptosis, senescence, repair mechanisms affect signalling pathways of drug target receptors. Alterations in complex pathways associated with growth factors, ion and nutrient transports and utilization, hormone responsiveness, oncogene and protein kinase signalling pathways, chromosome structure and gene expressions are in involved in drug resistance. The efflux mechanisms especially by efflux pumps like P-glycoprotein and the multidrug-resistance protein which belongs to Adenosine Triphosphate – Binding Cassette family are particularly important in multidrug resistance. There are various studies confirming the importance of genetic changes for acquired resistance during cancer chemotherapy. Mutational changes can be single step or multistep. In addition to genetic changes there are epigenetic changes or non mutational mechanisms which occur quickly in response to environmental changes.

Tumour growth rate along with phase and cell cycle specificity are other major factors that determine the sensitivity of cancer cells to chemotherapy. The growth of a neoplasm depends on several interrelated factors like normal cell cycle time, growth fraction, total number of cells in the population and the intrinsic cell death rate. Cells progress through a cell cycle comprising four phases: $G_1$, $S$, and $G_2$, $M$. At the end of the $G_2$, $M$ phase, cells divide and new cells begin their cycle in $G_1$. Cells remain in the quiescent phase $G_0$ (quiescence) in the absence of external changes, otherwise they may return to the proliferative cycle (at the first step of S phase). There are certain check points in between cell cycle phase transition, the most important of which occur at the G1=S and G2=M transitions. There are exchanges of cells between phases G0 and G1 all the time till restriction point occur at G1. Then the proliferation of cells continues until actual division. This can be prematurely interrupted by anticancer drugs. Many anticancer drugs cause direct damage to DNA, which triggers cellular checkpoints. The resistant cells survive and multiply and result in re growth of cancer cells not sensitive to the administered drug. Figure 1 depicts the cell cycle.
The cytotoxic effects of cancer drugs follow log cell kill kinetics. According to the log-cell-kill hypothesis constant fraction of tumour cells are eliminated\(^21\), i.e. Cell kill is proportional regardless of tumour burden. The viability and character of remaining tumour cells can be analysed by histological examination of residual tumour cells\(^22\). The experimental data in human solid cancers follows Gompertzian kinetics i.e., the growth fraction of tumour is not constant but decreases exponentially with time\(^22\). The location of tumour is in its particular growth curve determines the response to chemotherapy in drug sensitive tumour\(^23\). Figure 2 depicts log cell kill hypothesis\(^16, 21, 22\).

**DISCUSSION**

**a. Clinical significance of drug resistance**

The efficacy of a treatment regime is determined by the complete response rate\(^21\) and the relapse-free survival from the time treatment is discontinued. The relapse-free survival is the major end point in adjuvant programmes. If a patient is having good response to chemotherapy, further treatment need to be continued while a poor response points out the need to consider an alternative method of treatment\(^24\). Drug resistance in addition to reducing clinical effectiveness, result in early termination of treatment and reduced relapse free interval and survival.

**b. Measures for overcoming drug resistance**

There are various methods for overcoming these major disadvantages of cancer chemotherapy. Combination chemotherapy using conventional cytotoxic agents attain several important objectives not achieved with single agents\(^25\). It provides maximal cell killing with tolerable side effects and in addition can slow or prevent the development of resistance\(^26\). Principle of selection of drugs in an effective drug combination follows the following principle; like only drugs known to be partially effective against a given tumour when used alone should be selected; drug selection should be based on the spectrum of toxicities without any overlap in toxicities\(^21\). There should be a clear understanding of the biochemical, molecular and pharmacokinetic mechanisms of interaction between the individual drugs in a given combination to allow for maximal effect\(^16, 27\). Drug discovery efforts are now directed toward restoring apoptosis in tumour cells, as this process or their absences have profound influence on tumour cell sensitivity to drugs\(^28\). In high grade tumours although more aggressive, drugs are generally more effective in combination and may be synergistic through biochemical interactions\(^29\). New regimens are designed based on useful interactions\(^30\). When the drugs share common mechanism of resistance or have overlapping toxicities combinations are considered irrational\(^31\).

Tumour cells in population in patients with visible disease exceed 1 gm or 10\(^9\) cells and each cycle of therapy kills less than 99% of cells. So treatments are repeated with multiple cycles to effectively kill the entire tumour cells\(^32\). Optimal cancer drug scheduling is a way of controlling resistance to therapy. Control avenues of drug administration and dose intensification provide better outcome\(^16\).

**CONCLUSION**

Despite various strategies to overcome drug resistance, the problem especially multidrug resistance is still casting its shadow in successful treatment of cancer therapy. A better understanding of mechanism of drug resistance, its genetic and epigenetic links will open up new vistas in circumventing this problem and prolong the life expectancy of the patient.

**ACKNOWLEDGEMENT**

Authors acknowledge the great help received from the scholars whose articles cited and included in references of this manuscript. The author is also grateful to authors / editors /
publishers of all those articles, journals and books from where the literature for this article has been reviewed and discussed. Authors are grateful to IJCRR editorial board members and IJCRR team of reviewers who have helped to bring quality to this manuscript.

REFERENCES


Figure 1: Cell cycle
Figure 2: Log cell kill