Chapter 2

Review of Literature

Cardiovascular disease is considered as one of the foremost causes of death in developed countries (Caro, 1981) and that one of the most important cardiovascular diseases is atherosclerosis (Guyton, 1970). Atherosclerosis or stenosis development in the innermost arterial wall consists of three stages in general viz., (i) initial stage in which the intimal thickening starts, (ii) the growth stage in general viz., (iii) the severe stage which affects blood supply to the heart muscle. Atherosclerosis that is usually develops due to an abnormal growth at the lumen of an artery is now regarded as a rapidly increasing heart disease among different age groups. Further, stenosis which is associated with the changes in blood flow, flow patterns, pressure drop and resistance to flow (Liu et al., 2004; Poltern et al., 2006) is a type of vascular disease. There are a good many reports that hydrodynamic factors could play a very important role in the formation, development and progression of an arterial stenosis (Young and Tsai, 1973; Caro, 1981; Mates et al., 1978). It has also been reported that rheologic and fluid dynamic properties of both blood and blood flow, could play a significant role in the fundamental understanding, diagnosis and treatment of many cardiovascular and arterial diseases (Fry, 1968; Dintenfass, 1977; Chien, 1981; Lighthill, 1975; Roach, 1977). Also, a large number of investigations that have led to a better understanding of the flow disturbances induced by a stenosis, includes both theoretical works (Vand, 1948; Bloch, 1962; Brunn, 1975; Nubar, 1967) and experimental (Bugliarello and Hayden, 1962; Bannet, 1967) studies. In their work, several velocity profiles are obtained for the pulsatile flow through tubes with the constrictions of different symmetry and the degrees of blockage, by using the photochromic tracer methods (Ojha et al., 1989). Smith (1979) has conducted extensive studies of steady flows through an axi-symmetric stenosed artery, with using an analytical approach. This study has revealed that the resulting flow patterns are highly dependent on geometry of the stenosis and the overall Reynolds number of the flow. In their study, Deshpande et al. (1976) have employed the finite difference scheme to deal with the flow situation through an axi-symmetric stenosis, under steady flow. A study by
Young and Tsai (1973) have provided experimental analysis on steady flow through stenosed arteries with varying severity, stenosis length, axi-symmetric and asymmetric conditions, and with a range of Reynolds numbers from laminar to turbulent flows. It is found that all these factors have contributed significantly to the flow behaviour. Atherosclerosis alters this flow path and forces the flow to produce highly disturbed flow, which can be further aggravated by other diseased conditions that may alter artery or blood properties. Mukhopadhaya and Layek have carried out a systematic analysis of flow behavior in a two dimensional tube (modeled as an artery) with a locally variable shaped constrictions (Mukhopadhaya and Layek, 2008).

Later, some studies have shown that in order to approach realistic conditions, it is not possible to neglect the time-varying nature of the flow within the arteries. Other studies have thus included transient conditions into their simulations in order to take into account this flow behaviour. Imaeda and Goodman (1980) performed simulations on non-linear pulsatile blood flow in large arteries to determine the stability of the code and model used as well as to provide a proper representation of higher-frequency components. In addition, this code has attempted to account for the viscoelastic properties of the wall in terms of wall motion and the effect on the fluid. Misra and Chakravarty (1986) have also performed simulations of arteries incorporating stenosis and assuming blood as a Newtonian fluid. The effect of artery wall response was also incorporated into the simulation and fluid harmonic waves were studied. Many researchers have studied pulsatile blood flow for various flow situations. Womersly has investigated the pulsatile flow of blood in arteries by considering blood as a Newtonian, incompressible fluid, with a known pressure gradient which is a parabolic function of time (Womersly, 1955). In his model, the tube is taken to be linear, homogeneous, long, straight and freely moving and the analysis has been restricted in thin elastic tubes and with long wave approximations. Atabek and Lew have extended Womersly’s model by considering the tube to be subjected to initial stresses (Atabek and Lew, 1966). Arimen et al. have studied both steady and pulsatile flow models for micropolar fluid using constant slip condition for the red blood cells at the solid boundary and the expressions for the axial and rotational velocities are obtained, in the form of Bessel-Fourier series (Arimen et al.,
Debnath has studied the pulsatile flow of blood through rigid tubes with entrance effects, due to the impulsive action of an arbitrary as well as particular pressure gradient (Debnath, 1976). Mazumdar et al. have investigated the axial velocity distributions and the pressure gradient of the pulsatile flow of blood in a constricted rigid artery for various values of hematocrit and the Womersley parameter by considering blood as a Newtonian fluid (Mazumdar et al., 1996). A particle-fluid suspension model for pulsatile blood flow under periodic body acceleration has been investigated by the authors (Usha and Prema, 1999). A numerical and experimental investigation of unsteady entry flow in a curved tube, is presented in their work (Gijsen et al., 1999). Darpia and Das have analysed the pulsatile flow of blood in an eccentric catheterized artery by using a fast algorithm (Darpia and Das, 2002). Haldar has dealt with the problem of oscillatory blood flow through a rigid tube with mild constriction under a simple harmonic pressure gradient and has examined the effect of stenosis on the flow (Haldar, 1987). Aroesty and Gross have studied the pulsatile flow of blood in small blood vessels (Aroesty and Gross, 1972) and, Chaturani and Ponnalagar Samy extended this theory to study pulsatile flow of blood in stenosed arteries, with modeling blood by a Casson fluid (Chaturani and Ponnalagar Samy, 1986). Recently, a mathematical model for Herschel-Bulkley flow of blood in a constricted artery has been investigated by (Siddiqi et al., 2010). Also, Sankar has analysed the influence of periodic body acceleration on pulsatile flow of blood, treating blood as Herschel-Bulkley fluid (Sankar et al., 2010).

It is also reported that for several clinical and subclinical purposes, artificial catheters are now being widely used. The insertion of a catheter (a long flexible cylindrical tube) into a constricted tube (i.e. a stenosed artery) results in the formation of an annular region between the outer wall of the catheter and the cavity of an artery. The effect of catheterization on various flow parameters in a curved artery, is studied by Jayaraman and Tewari (Jayaraman and Tewari, 1995). In their model X-ray cinematography (the science of motion picture photography) is used to map the arterial lumen and for the perfusion of an artery. Roose and Lykoudis (Roose and Lykoudis, 1971) have studied the fluid mechanics of the ureter with an inserted catheter, by considering the peristaltic wave moving along the stationary cylinder. MacDonald (MacDonald, 1986) has
considered the pulsatile blood flow in a catheterized artery and obtained theoretical estimates for pressure gradient corrections for catheters, which are positioned eccentrically, as well as coaxially with the artery. The effect of catheterization on various flow characteristics in an artery with or without stenosis was studied by Karahalios (Karahalios, 1990). Dash et al. (1996) have considered the steady and pulsatile flow of the Casson fluid in a narrow artery when a catheter is inserted into it and estimated the increase in frictional resistance in the artery due to catheterization. Back et al. (1996) have estimated the flow blockage effects in the presence of a catheter using the in-vitro experimental evidences along with the angiographic data on the dimensions and shape of stenotic vessel segments before and after angioplasty. Srivastava and Srivastava (2009) have presented a brief review of the literature on artery catheterization with and without stenosis. Srivastava et al. (2010) have investigated the particle suspension model for blood flow through a stenosed catheterized artery. Sarojamma et al. have studied the flow of blood through a stenosed catheterized artery under the influence of body acceleration, by considering blood to behave as Casson fluid (Sarojamma et al., 2012).

The complex geometry of arteries (viz. bending, bifurcating, branching, tapering, discrete, inclined etc.) is also an important factor which obviously affects the local hemodynamics (Puniyani and Nimi, 1998; Guyton, 1970). The relationship between flow in the arteries, particularly the wall shear stresses, and the sites where atherosclerosis grows, has motivated many researchers on arterial flow in current years. There may not have any doubt that inclination in arteries, is a considerable side of mammalian arterial system and the formation of stenosis along the inclined wall, may alter the flow situation to a great extent. Vajravelu et al. (2005) have studied the peristaltic transport of Herschel-Bulkley fluid through an inclined tube. Maruti Prasad and Radhakrishnamcharya (2008) have proposed steady blood flow through an inclined non-uniform tube considering blood as a Herschel-Bulkley fluid. Recently, Chakraborty et al. (2011) have investigated a suspension model for blood flow in an inclined constricted artery.

Many researchers have investigated two-layered models, apart from one-layered model for blood flow inside an artery. Two-layered models of blood flow through stenosed arteries have been studied by Shukla et al. (1980). In their analysis, a cell-free peripheral
plasma layer and a core region which is a suspension of red cells in plasma, are considered. They have assumed blood in behaving as Newtonian or non-Newtonian fluids, in both the models. Chaturani and Samy (1982) have taken a two-layered model in which the peripheral plasma layer is Newtonian in character and the central core of red cell suspension in plasma, is represented by a Casson fluid. Shukla and co-workers (Shukla et al., 1980) have applied a two-fluid model to discuss the flow of blood through a stenosed artery. Sankar and Lee have reported the study of a two-fluid model of blood flow in a stenosed artery, by considering the body fluid blood as a Newtonian fluid in the core region and a Herschel-Bulkley fluid, in the peripheral plasma region (Sankar and Lee, 2007).

In view of above, we have considered some blood flow situations in successive chapters wherein the body fluid blood behaves as both Newtonian and non-Newtonian fluids.