8. Taurine and metabolic disease

Svend Høime Hansen¹ and Ole Hartvig Mortensen²

¹Department of Clinical Biochemistry, 3-01-1, Rigshospitalet, Copenhagen University Hospital
Blegdamsvej 9, DK-2100 Copenhagen, Denmark; ²Department of Biomedical Sciences
University of Copenhagen, Blegdamsvej 3, DK-2100 Copenhagen, Denmark

1.1. Introduction

Taurine is a sulfur-containing amino acid, which does not enter protein synthesis, and is traditionally considered as an inert molecule without any reactive groups. Besides the well-known conjugation with bile acids, taurine has a number of other physiological functions such as, intracellular osmolyte for volume regulation and some antioxidant properties (Bouckenooghe et al., 2006; Hansen, 2001; Huxtable, 1992; Jacobsen and Smith, 1968; Schuller-Levis and Park, 2003).

Taurine is thus not expected to be directly involved in metabolic pathways. Nevertheless, taurine deficiency in the cat results in a marked dysfunction of energy demanding tissues (i.e. retina and heart) (Sturman, 1993), and similar observations are seen in the taurine-transporter knockout mouse (Warskulat et al., 2007).

1.2. Taurine and glucose metabolism - diabetes

Taurine was first shown to have an effect upon glucose homeostasis in the 1930s (Ackermann and Heinsen, 1935), where it was reported to have a
hypoglycemic effect. Since then, a lot of studies have shown a clear interaction between taurine and diabetes, as described in recent literature reviews (Franconi et al., 2006; Hansen, 2001; Kim et al., 2007). Several hypotheses as to how this interplay is orchestrated have been proposed, as taurine has shown both developmental, osmoregulatory, anti-apoptotic, anti-inflammatory, and anti-oxidant effects as well as effects on lipid, cholesterol, and calcium homeostasis (Della Corte et al., 2002; Franconi et al., 2004; Lee et al., 2005; Schaffer et al., 2009).

1.2.1. Humans

In diabetic patients, taurine homeostasis is dysregulated, as type 1 diabetic patients have an increased urinary taurine excretion (Hermansson and Mårtensson, 1984) and both type 1 and type 2 diabetic patients have a decreased plasma taurine concentration (De Luca et al., 2001b, 2001a; Franconi et al., 1995). Furthermore, diabetes seem to cause long term changes in taurine homeostasis, as non-diabetic women who had gestational diabetes, but recovered, had a lower plasma taurine concentration several years after giving birth (Seghieri et al., 2007).

Relatively few studies have examined the effect of taurine supplementation upon glucose homeostasis in diabetic patients or patients predisposed for developing diabetes. Elizarova et al. found that taurine supplementation (0.5 g twice a day for 30 days) markedly decreased the average daily plasma glucose levels and glycosuria independently of insulin in type 1 diabetic patients (Elizarova and Nedosugova, 1996). In direct contradiction to this study, Chauncey et al. found no effect of taurine supplementation (1.5 g twice a day for 4 months) upon fasting glucose or HaemoglobinA1c (HbA1c) levels in type 2 diabetic patients (Chauncey et al., 2003). This finding is further corroborated by another study showing no effect of taurine supplementation (0.75 g twice a day for 8 weeks) on fasting glucose, glucose tolerance, fasting insulin and insulin sensitivity (as measured by euglycemic hyperinsulinemic clamp) in obese healthy subjects with a family history of type 2 diabetes (Brøns et al., 2004). Last, taurine supplementation (1 g three times a day for 2 weeks) of obese non-diabetic men did not have an effect on fasting plasma glucose, but taurine did prevent intralipid-infusion-induced insulin resistance (Xiao et al., 2008). However, these studies suffer from different limitations in their design making their interpretation difficult: All studies lack a control group of completely healthy subjects who receive only taurine, two studies has a very limited characterization of the subjects (Elizarova and Nedosugova, 1996; Chauncey et al., 2003), and one study lacks a placebo group (Elizarova and Nedosugova,
The study with the best design (double-blinded, randomized crossover study) examines subjects with a predominantly normal glucose tolerance (Brøns et al., 2004). Furthermore, in several taurine supplementation studies examining diabetic complications, differences in fasting plasma glucose, insulin or HbA1c after taurine supplementation were not reported (Franconi et al., 1996; Nakamura et al., 1999). Thus, whether or not taurine supplementation has a positive effect upon glucose homeostasis in human diabetic patients is at present impossible to ascertain and more clinical studies examining the effect of taurine upon glucose homeostasis in diabetic patients are needed.

1.2.2. Animal models

Whereas taurine homeostasis seems largely unaffected in streptozotocin induced type 1 diabetes in rats (Trachtman et al., 1992), a genetic model of type 2 diabetes, the Zucker fatty rat, shows increased taurine excretion in urine (Williams et al., 2005) as well as an increase in the plasma taurine concentration (Wijekoon et al., 2004). Furthermore, in high-fructose fed rats, a well-known model of type 2 diabetes, a decrease in plasma and liver taurine has been observed (Nandhini et al., 2005).

Several studies have shown that taurine protects β-cells against destruction induced by streptozotocin in rodents, with most studies showing a glucose lowering effect of taurine (Alvarado-Vásquez et al., 2003; Odetti et al., 2003; Di Leo et al., 2004; Song et al., 2003; Hansen, 2001). The same protective and glucose lowering effect was seen in studies on alloxan induced type 1 diabetes in both mice (Lim et al., 1998), rats (Gavrovskaya et al., 2008), and rabbits (Tenner et al., 2003; Winiarska et al., 2009). However, the exact mechanisms by which taurine protects the β-cells against destruction and lowers plasma glucose are largely unknown, but may be related to a general mitochondrial protective effect asserted by taurine (Han et al., 2004) or the recently reported taurine mediated remodeling of pancreatic islets (El Idrissi et al., 2009).

Taurine has shown a beneficial effect in several animal models of type 2 diabetes. In the Otsuka Long-Evans Tokushima Fatty (OLETF) rats and in high-fructose fed rats, taurine increased insulin sensitivity and reduced hyperglycemia (El Mesallamy et al., 2010; Harada et al., 2004a; Nakaya et al., 2000; Nandhini et al., 2005). However, taurine supplementation does not show an effect in all animal models of type 2 diabetes, as in the GK rats, taurine supplementation had no effect on plasma glucose levels (Nishimura et al., 2002). As in type 1 diabetes, the exact mechanism by which taurine exerts its effects upon glucose homeostasis in type 2 diabetes is largely
unknown, although the effect may be either tied together with the lipid lowering effect of taurine (as increased plasma lipids are associated with insulin resistance), by the effect of taurine upon insulin signaling (Nandhini et al., 2005; Takatani et al., 2004) or by a mitochondrial protective effect, as mitochondrial dysfunction seems to be associated with decreased insulin secretion (Mulder and Ling, 2009; Maechler et al., 2010) and insulin resistance (Kelley et al., 2002; Lowell and Shulman, 2005; Pagel-Langenickel et al., 2010). It may also be possible that the effect of taurine is mediated through its conjugation with bile acids, as a recent study showed that tauro-ursodeoxycholic acid, a chemical chaperone and a derivative of bile acids was found to protect against diet-induced insulin resistance by relieving ER stress (Ozcan et al., 2006). Furthermore, taurine may also be an important factor in regulation of the inflammatory response, as its normally occurring derivative, taurine chloramine, is a potent anti-inflammatory agent (Park and Schuller-Levis, 2003). Incidently, low-grade inflammation is thought to play a key role in the development of obesity induced type 2 diabetes (Lee and Pratley, 2005).

1.2.3. The C57BL/6J mouse

The mouse strain C57BL/6J (or just B6) is one of the most widely-used animal models for understanding metabolic diseases, especially concerning lipid metabolism and atherosclerosis and when reporting the mouse genome, this mouse strain was chosen as the reference strain. C57BL/6J is also very susceptible to development of obesity and atherosclerosis when using a high fat diet (Nishina et al., 1990, 1993; Paigen et al., 1985). Based on data from July 2010 approximately 50% of all genetically modified mouse strains in the Mouse Genome Informatics database (http://www.informatics.jax.org) are based on this strain.

In the 1950s, a defect in the taurine renal reabsorption was reported for the C57BL/6J mouse strain (Harris and Searle, 1953), and further characterisation of the transporter defect was done in the 1970s and 1980s (Chesney et al., 1976; Jean et al., 1984; Mandla et al., 1988; Rozen et al., 1983). Later genetic studies have not been reported. When interpreting the results of studies using transgenic mice, the effect of taurine is only discussed in specific taurine supplementation studies, but taurine could play the role as silent partner, especially for metabolic studies in transgenic models back crossed to C57BL/6J mice. In terms of supplementation studies in C57BL/6J mice, the taurine effects could possibly be interpreted as compensation for the renal absorption defect. Whether or not the difference in taurine homeostasis between mice strains is important for glucose homeostasis remains to be
Figure 1. Possible mechanisms by which taurine exerts its anti-diabetic effect as well as possible target tissues. AGE) advanced glycation end products.

Determined. However there is a striking difference in glucose homeostasis and insulin response in different mice strains as well as their responsiveness to a high fat diet (Andrikopoulos et al., 2005; Berglund et al., 2008; Funkat et al., 2004; Kaku et al., 1988).

1.3. Taurine and diabetic complications

A number of long-term complications typically accompany the general metabolic dysfunction in diabetes (Hansen, 2001). Most serious for the patients are possibly the vascular complications. Diabetic retinopathy: Microvascular complications in the eyes lead to damage of the retina, and thus reduced visual field or in the worst case blindness. Diabetic neuropathy: Dysfunction of the peripheral nerves causing diverse symptoms and neural dysfunction. Diabetic nephropathy can lead to chronic renal failure and subsequent need for haemodialysis. Besides, some of the macrovascular complications can be fatal, e.g. cardiomyopathy and atherosclerosis (see below). The diabetic vascular complications have all been related to dysfunction of the endothelium. A recent study on young male type 1 diabetes patients demonstrated that taurine supplementation can reverse the endothelial dysfunction (Moloney et al., 2010).
One of the suggested hypotheses for understanding the microvascular diabetic late complications is based on the so-called sorbitol pathway and subsequent osmolyte depletion hypothesis. The hypothesis is based on the fact that high glucose levels lead to intracellular sorbitol accumulation due to aldose reductase. Sorbitol cannot in itself be transported across the cellular membrane, and thus more labile osmolytes like taurine or myo-inositol will gradually be depleted from the intracellular environment. Finally, the sorbitol-producing cells will swell due to impaired volume regulation and dysregulation of the taurine transporter (Askwith et al., 2009; Hansen, 2001; Stevens et al., 1993). Furthermore additional taurine depletion can be caused by intracellular scavenging of reactive carbonyl compounds and thus prevention of AGE formation (Hansen, 2001).

The weakness of this hypothesis based on the sorbitol accumulation and taurine depletion is the fact that it gives no direct biochemical link to the cellular dysfunction observed in the diabetic complications. It should be noted

![Figure 2](image.png)

**Figure 2.** Simplified model for development of diabetic complications. Hyperglycemia causes sorbitol accumulation in the aldose reductase containing cells. This causes a gradual depletion of transportable osmolytes like taurine. Consequently, cell volume regulation becomes dysfunctional in the tissue. The process is accompanied by a slow intracellular depletion of taurine from the mitochondrial compartment resulting in increasing mitochondrial dysfunction.
that the types of tissue and organs involved in diabetic complications are all very energy-demanding, and when comparing the clinical manifestations of diabetic complications with those found in patients with mitochondrial diseases (Kisler et al., 2010), major correspondence can be found. However, it must be reasonable to assume that a gradual taurine depletion in the intracellular environment will be expected to be accompanied by mitochondrial depletion of taurine. Accepting taurine as a necessary compound for mitochondrial function (see below), either as matrix pH buffer (Hansen et al., 2006, 2010) and/or as a requirement for mitochondrial translation being found in mitochondrial tRNA (Suzuki et al., 2002; Schaffer et al., 2009), taurine depletion can possibly be a direct cause of mitochondrial dysfunction. This mitochondrial role of taurine should thus be included in the suggested viewpoint (Brownlee, 2005) of mitochondrial dysfunction as a possible unifying hypothesis for diabetic complications.

1.4. Taurine and lipid metabolism – obesity

1.4.1. Cholesterol catabolism and bile acids

In most physiology and biochemistry text books, taurine is mentioned solely as a component of the bile acids. Cholesterol catabolism and subsequent excretion from the body occurs through the bile acids as the major metabolic pathway (see Figure 3). Cholesterol is oxidized in the liver to cholic acid by a complex enzyme framework (Russell, 2003). Cholic acid is subsequently conjugated with either taurine or glycine predominantly in the hepatocyte peroxisomes (Ferdinandusse et al., 2009; Solaas et al., 2000) by the enzyme bile acid-CoA:amino acid N-acyltransferase (BAAT) (Falany et al., 1994; He et al., 2003; Sfakianos et al., 2002). Species differences in the amount of bile acids conjugated to glycine or taurine exist. Thus, in rat, hamster, pig, and human the enzyme is capable of performing taurine as well as glycine conjugation. In cat and rat, taurine conjugation is almost exclusively performed, and in mouse and dog, only taurine conjugation occurs (Falany et al., 1997; He et al., 2003; Kwakye et al., 1991; Rabin et al., 1976; Sfakianos et al., 2002; Trautwein et al., 1999). In the rabbit only glycine conjugation has traditionally been reported (Wildgrube et al., 1986), but findings in a more recent study raises doubt about this fact (Hagey et al., 1998).

Animal experiments in rats have demonstrated that taurine supplementation can alleviate the consequences of a high cholesterol diet by enhancing the excretion of bile acids, either due to enhanced activity of the hepatic 7α-hydroxylase (Nishimura et al., 2003), enhancement by taurine of bile acid conjugation (Sugiyama et al., 1989), and/or by inhibiting the ileal
bile acid reabsorption (Nishimura et al., 2009). Similar studies have been performed in rabbits, but as rabbits almost exclusively conjugate bile acids with glycine, taurine supplementation studies in rabbit on cholesterol metabolism (Balkan et al., 2002, 2004) are difficult to interpret.

Only a few human studies, all with a small number of participating subjects (N=3-11), seem to exist on taurine supplementation, subsequent bile acid turnover and lipid metabolism (Hepner et al., 1973; Hardison and Grundy, 1983; Sjovall, 1959; Truswell et al., 1965; Tanno et al., 1989). It seems clear that in humans, taurine is the preferred partner in bile acid conjugation compared with glycine, as taurine supplementation clearly increases the taurine/glycine conjugation ratio in the studies. As the bile acids are the main way of cholesterol excretion from the body, the relative proportions of the taurine or glycine conjugation are of interest, as relative differences in the

![Figure 3. Overview of the bile acid production, bile acid conjugation with either glycine or taurine by the bile acid CoA:amin acid:N-acyltransferase (BAAT) enzyme, intestinal bile acid reabsorption and partly fecal excretion.](image-url)
reabsorption of the conjugates are expected, as the water solubility is better for taurocholate due to the sulfonic acid group in taurine.

Taurine-conjugated bile acids are readily reabsorbed in the intestine by an active ileal transport (Krag and Phillips, 1974), so a larger circulating bile acid pool becomes the first result of taurine supplementation. However, it is reasonable to assume that the reabsorption becomes down-regulated through a feedback mechanism from the circulating bile acids as in the rat (Nishimura et al., 2009) and then enhanced excretion of cholesterol will ensue. Alternately, the human studies could indicate that the increased circulating levels of bile acids (including taurocholate) would downregulate the cholesterol biosynthesis. Furthermore, bile acids and bile acid receptors have been found to participate in metabolic regulation. Such effects of bile acids can be found reviewed elsewhere (Lefebvre et al., 2009; Staels et al., 2010; Trauner et al., 2010). Finally, it should be noted that a reported stimulation by tauroconjugation on fecal bacterial degradation of cholic acid (Van Eldere et al., 1996) could actually cause an increase of excretion of cholic acid by taurine.

1.5. Lipid metabolism

The direct involvement of taurine in cholesterol catabolism seems to have made the majority of taurine studies to concentrate on cholesterol levels, lipid accumulation and atherosclerotic lesions in the vessels (Kondo et al., 2001; Militante and Lombardini, 2004; Murakami et al., 1999). A few studies in mouse, hamster, rat or recently quail have included quantitative determinations of lipids and/or triglycerides in plasma, liver tissue or fat deposition (Gandhi et al., 1992; Harada et al., 2004b; Kondo et al., 2001; Murakami et al., 2002, 2010; Mochizuki et al., 1999; Nakaya et al., 2000; Sethupathy et al., 2002; Tsuboyama-Kasaoka et al., 2006; Yokogoshi and Oda, 2002; Yan et al., 1993). Generally taurine supplementation causes a decrease in plasma lipids and triglycerides. It should specifically be noticed that taurine supplementation could reverse obesity and increase energy expenditure in C57BL/6J mice fed a high-fat diet (Tsuboyama-Kasaoka et al., 2006).

A clinical study with taurine supplementation to a minor group of overweight or obese non-diabetic subjects found a minor decrease in plasma triglycerides, but no change in plasma cholesterol (Zhang et al., 2004). In one study (Mochizuki et al., 1999) no effect of taurine supplementation was found on the liver lipids, but a minor decrease was observed on liver cholesterol. In all the other studies, taurine supplementation demonstrated a clear decrease in lipid and triglyceride levels. Finally, an epidemiologic
cohort study has shown that urinary taurine excretion (due to intake of fish and shellfish) was inversely correlated to the risk of developing atherosclerosis (Yamori, 2004, 2006). No explanation was presented in any of the studies for the possible biochemical role of taurine.

As discussed in the previous section taurine supplementation must be expected to increase the bile acid pool and thus improve bile acid-assisted lipid transport mechanisms and associated metabolic regulation. Alternately, taurine supplementation could be interpreted to enhance the mitochondrial oxidation of fatty acids. Following this argumentation, the observed improvements of lipid metabolism could be considered as support for the recently presented hypothesis of taurine as mitochondrial matrix pH buffer. Taurine supplementation will increase matrix pH buffering capacity and thus stabilise the oxidative environment in the mitochondrial matrix to reduce release of reactive oxygen species (ROS), and perhaps even more important stabilise the very pH-dependent beta-oxidation of the fatty acids by the acyl-CoA dehydrogenase enzymes (Hansen et al., 2006, 2010).

1.6. Taurine and fetal programming of metabolic disease

During the last two decades, it has become apparent that nutrition and environment during pregnancy and early life have a lasting effect upon the metabolic phenotype in adult life. The idea that there is a link between early life conditions and subsequent disease was already discovered in the 1930s (Smith and Kuh, 2001). However, it was not until Barker in 1986 reported a correlation between childhood nutrition and ischemic heart disease (Barker and Osmond, 1986) and in subsequent studies Barker and Hales during the early 1990s coined the “thrifty phenotype” hypothesis (Hales and Barker, 1992) that the correlation was rediscovered. The hypothesis suggests that early pre- and postnatal life is a critical period during which environmental exposures that hinder growth will lead to an adaptation of metabolism to a limited supply of nutrients, or other types of growth restraints. This adaptation will contribute to increased risk for disease in adult life if sufficient nutrients are provided. The term “fetal programming” can be used to describe the hypothesized, yet unknown, mechanism behind the “thrifty phenotype” hypothesis (Desai and Hales, 1997; Hales and Barker, 2001).

Several human studies have thus convincingly shown that fetal malnutrition during pregnancy, which often leads to low birth weight or a small for gestational age fetus, confers an increased risk of obesity, insulin resistance, type 2 diabetes and a general low life expectancy (Jones and Ozanne, 2009; Poulsen et al., 1997; Ravelli et al., 1999; Roseboom et al., 2001a, 2001b). Several animal models in species ranging from rodents to
monkeys and of fetal malnutrition or low birth weight has been used to study fetal programming, or intrauterine growth retardation (IUGR), with some of the most popular ones being protein or dietary restriction during gestation, intrauterine artery ligation and dexamethasone treatment of the pregnant dam (Martin-Gronert and Ozanne, 2007). Human IUGR exhibit decreased taurine levels in the fetus (Cetin et al., 1990; Economides et al., 1989), something which is reflected in animal models of IUGR as well (Reusens et al., 1995; Wu et al., 1998).

Taurine is considered to be an essential amino acid during development, as the endogenous synthesis of taurine is inadequate in the fetus (Hibbard et al., 1990). Thus, the fetus is dependent on the maternal supply of taurine. Taurine deficiency leads to a smaller birth weight in both cats (Sturman, 1991) and rodents (Ejiri et al., 1987). The offspring of cats (which are unable to synthesize taurine) reared on a taurine free diet, exhibit profound developmental abnormalities, among these being: Smaller body weight, smaller brain weight, abnormal hind leg development as well as a degeneration or abnormal development of the retina and visual cortex (Sturman, 1991). Furthermore, mice deficient in the taurine transporter gene (TauT), show a smaller overall size, however no information regarding birthweight is available (Warskulat et al., 2007). TauT knockout mice also show defects in heart and skeletal muscle development, most likely due to mitochondrial effects (Ito et al., 2008; Warskulat et al., 2004). In humans, a low plasma taurine concentration in the infant has been linked to detrimental mental development (Heird, 2004; Wharton et al., 2004), something which has been corroborated by animal studies (Sturman, 1993). Furthermore, taurine supplementation in mice has shown that the exact timing of taurine supplementation during brain development influence the learning ability, with taurine sufficiency being most important during the perinatal and postnatal period (Suge et al., 2007). Experimental animal studies suggest that taurine may be a marker of fetal well being (de Boo and Harding, 2007).

Several studies have documented that taurine ameliorates some of the harmful effects that detrimental fetal programming may confer upon the offspring in terms of the risk of developing metabolic disease and notably, taurine is able to at least partially prevent an experimental induced decrease in birth weight in several animal models of fetal programming. Thus, taurine supplementation has been shown to normalize proliferation and vascularization of the pancreas following gestational protein restriction (Boujendar et al., 2002, 2003) and to decrease the sensitivity of the pancreas towards cytokines (Merezak et al., 2001, 2004). In fact, taurine prevented all changes in mRNA expression levels in the pancreas in newborns caused by gestational protein restriction (Reusens et al., 2008). Likewise, taurine
prevented a large portion of the changes in mRNA expression levels in both skeletal muscle and liver caused by gestational protein restriction (Mortensen et al., 2010). Interestingly these studies of the fetal gene expression profile in both pancreas, liver and skeletal muscle suggest that the rescue effect taurine exerts may have a mitochondrial component. This may also be important in human development, as a reduced activity of the placental taurine transporters has been observed in low birth weight in humans (Norberg et al., 1998), something which may explain the low taurine concentrations in fetal plasma often observed in this pregnancy complication (Cetin et al., 1990). A recent study suggest that excessive taurine during gestation may also have detrimental effects later in life, as taurine supplementation of pregnant rats resulted in increased obesity and insulin resistance in the offspring (Hultman et al., 2007). Collectively these studies suggest that taurine has a programming

![Figure 4.](image) The different pathways by which taurine supplementation influences fetal programming mediated development of type 2 diabetes.
or rescuing effect during fetal development, perhaps via epigenetic and/or organogenesis related mechanisms.

1.7. Taurine, mitochondrial function and metabolic disease – the missing link?

Recently, taurine has been suggested to have an important role in the mitochondria as it has been suggested as a pH buffer in the mitochondrial matrix to stabilize mitochondrial beta-oxidation of fatty acids. This oxidative process requires mildly alkaline conditions in the mitochondrial matrix with taurine as optimal pH buffer (Hansen et al., 2006, 2010). In addition, taurine could have a direct role in the metabolic regulation of the pyruvate dehydrogenase (Lombardini, 1998). Besides, taurine may be required for optimal mitochondrial protein synthesis through taurine modified tRNAs (Suzuki et al., 2002; Schaffer et al., 2009). High mitochondrial taurine concentrations immediately explains the pivotal requirement for taurine during fetal development (Suzuki et al., 2002), especially for the strongly oxidative and thus mitochondria-rich tissues like liver and skeletal muscle as well as pancreatic β-cells. Consequently, taurine deficiency either during development or adult life may cause impaired mitochondrial oxidation, fatty acid oxidation and altered mitochondrial protein synthesis.

The role of mitochondrial dysfunction in insulin resistance and type 2 diabetes is debated and may actually be a consequence of insulin resistance rather than a causal factor (Abdul-Ghani and DeFronzo, 2010; Dumas et al., 2009; Holloszy, 2009; Schiff et al., 2009; Schrauwen et al., 2010; Turner and Heilbronn, 2008). However, many studies have found a correlation between decreased mitochondrial function or amount, or gene expression patterns and type 2 diabetes. In addition, a recent viewpoint (Brownlee, 2005) has suggested mitochondrial dysfunction as a possible unifying hypothesis for diabetic complications. Hence, taurine deficiency as seen in diabetes may increase the mitochondrial dysfunction and/or be involved in a vicious cycle that ultimately lead to a worsening of the diabetic condition and mitochondrial function. Thus it will be important in to examine the TauT knockout mice in terms of susceptibility to diet induced type 2 diabetes.

1.7.1. Therapeutic perspectives for taurine as supplementation

Several animal studies have demonstrated positive effect on cholesterol and lipid metabolism with subsequent prevention in the development of atherosclerosis. These studies strongly support the idea of using taurine for alleviating impaired lipid metabolism in atherosclerosis, type 2 diabetes and
obesity. The arguments for using taurine to prevent diabetic complication are also convincing, possibly in combination with aldose reductase inhibitors, as taurine uptake in the affected cells might be prevented due to sorbitol accumulation, which can be prevented with these inhibitors.

Taurine is today available as supplementation or in high concentrations in energy drinks like the Austrian brand Red Bull or the Japanese brand Lipovitan. However, the availability as commercial consumer products also seems to represent a hindrance for establishing health recommendations with regards to daily intake of taurine, as the number of associated clinical metabolism studies is very limited. Even a recent meta-analysis on the role of taurine in development and growth from Cochrane (Verner et al, 2007) does not include any convincing biochemical arguments.

We hope that this review encourages future research, as the therapeutic perspectives of the presented hypotheses need to be tested.

1.8. References


