Microvascular and Macrovascular Complications of Diabetes

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Diabetes is a group of chronic diseases characterized by hyperglycemia. Chronic hyperglycemia injures the human body in many different ways. Modern medical care therefore uses a vast array of lifestyle and pharmaceutical interventions aimed at preventing and controlling hyperglycemia. One of the chief injuries arising from hyperglycemia is injury to vasculature, which is classified as either small vascular injury (microvascular disease) or injury to the large blood vessels of the body (macrovascular disease). As medical science advances increasingly toward prevention of complications of diabetes, it is important for clinicians to be familiar with the relationship between diabetes control and vascular injury.

Microvascular Complications of Diabetes

Diabetic retinopathy

Diabetic retinopathy may be the most common microvascular complication of diabetes. It is responsible for ~10,000 new cases of blindness every year in the United States alone.1 The risk of developing diabetic retinopathy or other microvascular complications of diabetes depends on both the duration and the severity of hyperglycemia. Development of diabetic retinopathy in patients with type 2 diabetes was found to be related to both the severity of hyperglycemia and the presence of hypertension in the U.K. Prospective Diabetes Study (UKPDS), and most patients with type 1 diabetes develop evidence of retinopathy within 20 years of diagnosis.2,3 Retinopathy may begin to develop as early as 7 years before the diagnosis of diabetes in patients with type 2 diabetes.1 There are several proposed pathological mechanisms by which diabetes may lead to development of retinopathy.

Aldose reductase may play a role in the development of diabetes complications. Aldose reductase is the initial enzyme in the intracellular polyol pathway. This pathway involves the conversion of glucose into glucose alcohol (sorbitol). High glucose levels increase the flux of sugar molecules through the polyol pathway, which causes sorbitol accumulation in cells. Osmotic stress from sorbitol accumulation has been postulated as an underlying mechanism in the development of diabetic microvascular complications, including diabetic retinopathy. In animal models, sugar alcohol accumulation has been linked to microaneurysm formation, thickening of basement membranes, and loss of pericytes. Treatment studies with aldose reductase inhibitors, however, have been disappointing.1,4,5

Cells are also thought to be injured by glycoproteins. High glucose concentrations can promote the nonenzymatic formation of advanced glycation end products (AGEs). In animal models, these substances have also been associated with formation of microaneurysms and pericyte loss. Evaluations of AGE inhibitors are underway.1

Oxidative stress may also play an important role in cellular injury from hyperglycemia. High glucose levels can stimulate free radical production and reactive oxygen species formation. Animal studies have suggested that treatment with antioxidants such as vitamin E may attenuate some vascular dysfunction associated with diabetes, but treatment with antioxidants has not yet been shown to alter the development or progression of retinopathy or other microvascular complications of the disease.1,6

Growth factors, including vascular endothelial growth factor (VEGF), growth hormone, and transforming growth factor beta, have also been postulated to play important roles in the development of diabetic retinopathy. VEGF production is increased in diabetic retinopathy, possibly in response to hypoxia. In animal models, suppression of VEGF production is associated with less progression of retinopathy.1,3,7

Diabetic retinopathy is generally classified as either background or proliferative. It is important to
have a general understanding of the features of each to interpret eye examination reports and advise patients about disease progression and prognosis.

Background retinopathy includes such features as small hemorrhages in the middle layers of the retina. They clinically appear as “dots” and therefore are frequently referred to as “dot hemorrhages.” Hard exudates are caused by lipid deposition that typically occurs at the margins of hemorrhages. Microaneurysms are small vascular dilatations that occur in the retina, often as the first sign of retinopathy. They clinically appear as red dots during retinal examination. Retinal edema may result from microvascular leakage and is indicative of a compromised blood-retinal barrier. The appearance is one of grayish retinal areas. Retinal edema may require intervention because it is sometimes associated with visual deterioration.

Proliferative retinopathy is characterized by the formation of new blood vessels on the surface of the retina and can lead to vitreous hemorrhage. White areas on the retina (“cotton wool spots”) can be a sign of impending proliferative retinopathy. If proliferation continues, blindness can occur through vitreous hemorrhage and traction retinal detachment. With no intervention, visual loss may occur. Laser photocoagulation can often prevent proliferative retinopathy from progressing to blindness; therefore, close surveillance for the existence or progression of retinopathy in patients with diabetes is crucial.

Diabetic nephropathy
Diabetic nephropathy is the leading cause of renal failure in the United States. It is defined by proteinuria of > 500 mg in 24 hours in the setting of diabetes, but this is preceded by lower degrees of proteinuria, called “microalbuminuria.” Microalbuminuria is defined as albumin excretion of 30–299 mg/24 hours. Without intervention, diabetic patients with microalbuminuria typically progress to proteinuria and overt diabetic nephropathy. This progression occurs in both type 1 and type 2 diabetes.

As many as 7% of patients with type 2 diabetes may already have microalbuminuria at the time they are diagnosed with diabetes. In the European Diabetes Prospective Complications Study, the cumulative incidence of microalbuminuria in patients with type 1 diabetes was ~12% during a period of 7 years. In the UKPDS, the incidence of microalbuminuria was 2% per year in patients with type 2 diabetes, and the 10-year prevalence after diagnosis was 25%. Pathological changes to the kidney include increased glomerular basement membrane thickness, microaneurysm formation, mesangial nodule formation (Kimmelsteil-Wilson bodies), and other changes. The underlying mechanism of injury may also involve some or all of the same mechanisms as diabetic retinopathy.

Screening for diabetic nephropathy or microalbuminuria may be accomplished by either a 24-hour urine collection or a spot urine measurement of microalbumin. Measurement of the microalbumin-to-creatinine ratio may help account for concentration or dilution of urine, and spot measurements are more convenient for patients than 24-hour urine collections. It is important to note that falsely elevated urine protein levels may be produced by conditions such as urinary tract infections, exercise, and hematuria.

Initial treatment of diabetic nephropathy, as of other complications of diabetes, is prevention. Like other microvascular complications of diabetes, there are strong associations between glucose control (as measured by A1C) and the risk of developing diabetic nephropathy. Patients should be treated to the lowest safe glucose level that can be obtained to prevent or control diabetic nephropathy. Treatment with ACE inhibitors has not been shown to prevent the development of microalbuminuria in patients with type 1 diabetes, but it has been shown to decrease the risk of developing nephropathy and cardiovascular events in patients with type 2 diabetes.

In addition to aggressive treatment of elevated blood glucose, patients with diabetic nephropathy benefit from treatment with antihypertensive drugs. Renin-angiotensin system blockade has additional benefits beyond the simple blood pressure–lowering effect in patients with diabetic nephropathy. Several studies have demonstrated renoprotective effects of treatment with ACE inhibitors and angiotensin receptor blockers (ARBs), which appear to be present independent of their blood pressure–lowering effects, possibly because of decreasing intraglomerular pressure. Both ACE inhibitors and ARBs have been shown to decrease the risk of progression to macroalbuminuria in patients with microalbuminuria by as much as 60–70%. These drugs are recommended as the first-line pharmacological treatment of microalbuminuria, even in patients without hypertension.

Similarly, patients with macroalbuminuria benefit from control of hypertension. Hypertension control in patients with macroalbuminuria from diabetic kidney disease slows decline in glomerular filtration rate (GFR). Treatment with ACE inhibitors or ARBs has been shown to further decrease the risk of progression of kidney disease, also
independent of the blood pressure–
lowering effect.

Combination treatment with an
ACE inhibitor and an ARB has been
shown to have additional renoprotective
effects. It should be noted that patients
treated with these drugs (especially in combination) may
experience an initial increase in creatinine and must be monitored for
hyperkalemia. Considerable increase in creatinine after initiation of these
agents should prompt an evaluation for renal artery stenosis.9,14

Diabetic neuropathy
Diabetic neuropathy is recognized by
the American Diabetes Association
(ADA) as “the presence of symptoms
and/or signs of peripheral nerve
dysfunction in people with diabetes
after the exclusion of other causes.”15
As with other microvascular
complications, the risk of developing
diabetic neuropathy is proportional to
both the magnitude and duration of
hyperglycemia, and some individuals
may possess genetic attributes that
affect their predisposition to develop-
ing such complications.

The precise nature of injury to
the peripheral nerves from hyper-
glycemia is not known but likely is
related to mechanisms such as polyol
accumulation, injury from AGEs,
and oxidative stress. Peripheral
neuropathy in diabetes may manifest
in several different forms, including
sensory, focal/multifocal, and
autonomic neuropathies. More than
80% of amputations occur after foot
ulceration or injury, which can result
from diabetic neuropathy.16 Because
of the considerable morbidity and
mortality that can result from dia-
betic neuropathy, it is important for
clinicians to understand its manifes-
tations, prevention, and treatment.

Chronic sensorimotor distal sym-
metric polyneuropathy is the most
common form of neuropathy in dia-
betes. Typically, patients experience
burning, tingling, and “electrical”
pain, but sometimes they may expe-
rience simple numbness. In patients
who experience pain, it may be worse
at night. Patients with simple numb-
ness can present with a painless foot
ulceration, so it is important to real-
ize that a lack of symptoms does not
rule out the presence of neuropathy.

Physical examination reveals
sensory loss to light touch, vibration,
and temperature. Abnormalities
in more than one test of periph-
eral sensation are > 87% sensitive
in detecting the presence of neu-
ropathy. Patients also typically
experience loss of ankle reflex.16
Patients who have lost 10-g monofil-
ament sensation are at considerably
elevated risk for developing foot
ulceration.17

Pure sensory neuropathy is
relatively rare and associated with
periods of poor glycemic control or
considerable fluctuation in diabetes
control. It is characterized by iso-
lated sensory findings without signs
of motor neuropathy. Symptoms are
typically most prominent at night.16

Mononeuropathies typically
have a more sudden onset and
involve virtually any nerve, but
most commonly, the median, ulnar,
and radial nerves are affected.
Cranial neuropathies have been
described but are rare. It should be
noted that nerve entrapment occurs
frequently in the setting of diabetes.
Electrophysiological evaluation in
diabetic neuropathy demonstrates
decreases in both amplitude of nerve
impulse and conduction but may
be useful in identifying the loca-
tion of nerve entrapment. Diabetic
amyotrophy may be a manifestation
of diabetic mononeuropathy and
is characterized by severe pain and
muscle weakness and atrophy, usu-
ally in large thigh muscles.16

Several other forms of neu-
ropathy may mimic the findings in
diabetic sensory neuropathy and
mononeuropathy. Chronic inflam-
matory polyneuropathy, vitamin
B12 deficiency, hypothyroidism,
and uremia should be ruled out in
the process of evaluating diabetic
peripheral neuropathy.16

Diabetic autonomic neuropathy
also causes significant morbidity and
even mortality in patients with dia-
betes. Neurological dysfunction may
occur in most organ systems and
can be manifest by gastroparesis,
constipation, diarrhea, anhidro-
sis, bladder dysfunction, erectile
dysfunction, exercise intolerance,
resting tachycardia, silent ischemia,
and even sudden cardiac death.16
Cardiovascular autonomic dysfunc-
tion is associated with an increased
risk of silent myocardial ischemia
and mortality.18

There is no specific treatment of
diabetic neuropathy, although many
drugs are available to treat its symp-
toms. The primary goal of therapy
is to control symptoms and prevent
worsening of neuropathy through
improved glycemic control. Some
studies have suggested that control
of hyperglycemia and avoidance of
glycemic excursions may improve
symptoms of peripheral neuropa-
thy. Amitriptyline, imiprime,
paroxetine, citalopram, gabapentin,
pregablin, carbamazepine, topira-
mate, duloxetine, tramadol, and
oxycodone have all been used to
treat painful symptoms, but only
duloxetine and pregablin possess
official indications for the treat-
ment of painful peripheral diabetic
neuropathy.16 Treatment with some
of these medications may be limited
by side effects, and no single drug is
universally effective. Treatment of
autonomic neuropathy is targeted
toward the organ system that is
affected but also includes optimiza-
tion of glycemic control.
Macrovascular Complications of Diabetes

The central pathological mechanism in macrovascular disease is the process of atherosclerosis, which leads to narrowing of arterial walls throughout the body. Atherosclerosis is thought to result from chronic inflammation and injury to the arterial wall in the peripheral or coronary vascular system. In response to endothelial injury and inflammation, oxidized lipids from LDL particles accumulate in the endothelial wall of arteries. Angiotensin II may promote the oxidation of such particles. Monocytes then infiltrate the arterial wall and differentiate into macrophages, which accumulate oxidized lipids to form foam cells. Once formed, foam cells stimulate macrophage proliferation and attraction of T-lymphocytes, which in turn induce smooth muscle proliferation in the arterial walls and collagen accumulation. The net result of the process is the formation of a lipid-rich atherosclerotic lesion with a fibrous cap. Rupture of this lesion leads to acute vascular infarction.19

In addition to atheroma formation, there is strong evidence of increased platelet adhesion and hypercoagulability in type 2 diabetes. Impaired nitric oxide generation and increased free radical formation in platelets, as well as altered calcium regulation, may promote platelet aggregation. Elevated levels of plasminogen activator inhibitor type 1 may also impair fibrinolysis in patients with diabetes. The combination of increased coagulability and impaired fibrinolysis likely further increases the risk of vascular occlusion and cardiovascular events in type 2 diabetes.20

Diabetes increases the risk that an individual will develop cardiovascular disease (CVD). Although the precise mechanisms through which diabetes increases the likelihood of atherosclerotic plaque formation are not completely defined, the association between the two is profound. CVD is the primary cause of death in people with either type 1 or type 2 diabetes.21,22 In fact, CVD accounts for the greatest component of health care expenditures for people with diabetes.22,23

Among macrovascular complications, coronary heart disease has been associated with diabetes in numerous studies beginning with the Framingham study.24 More recent studies have shown that the risk of myocardial infarction (MI) in people with diabetes is equivalent to the risk in nondiabetic patients who have already had an MI.25 These discoveries have led to new recommendations by the ADA and American Heart Association that diabetes be considered a coronary artery disease risk equivalent rather than a risk factor.26

Type 2 diabetes typically occurs in the setting of the metabolic syndrome, which also includes abdominal obesity, hypertension, hyperlipidemia, and increased coagulability. These other factors can also act to promote CVD. Even in this setting of multiple risk factors, type 2 diabetes acts as an independent risk factor for the development of ischemic disease, stroke, and death.27 Among people with type 2 diabetes, women may be at higher risk for coronary heart disease than men. The presence of microvascular disease is also a predictor of coronary heart events.28

Diabetes is also a strong independent predictor of risk of stroke and cerebrovascular disease, as in coronary artery disease.29 Patients with type 2 diabetes have a much higher risk of stroke, with an increased risk of 150–400%. Risk of stroke-related dementia and recurrence, as well as stroke-related mortality, is elevated in patients with diabetes.29

Patients with type 1 diabetes also bear a disproportionate burden of coronary heart disease. Studies have shown that these patients have a higher mortality from ischemic heart disease at all ages compared to the general population. In individuals > 40 years of age, women experience a higher mortality from ischemic heart disease than men.21 Observational studies have shown that the cerebrovascular mortality rate is elevated at all ages in patients with type 1 diabetes.30

The increased risk of CVD has led to more aggressive treatment of these conditions to achieve primary or secondary prevention of coronary heart disease. Studies in type 1 diabetes have shown that intensive diabetes control is associated with a lower resting heart rate and that patients with higher degrees of hyperglycemia tend to have a higher heart rate, which is associated with higher risk of CVD.31 Even more conclusively, the Diabetes Control and Complications Trial/Epidemiology of Diabetes Interventions and Complications Study demonstrated that during 17 years of prospective analysis, intensive treatment of type 1 diabetes, including lower A1C, is associated with a 42% risk reduction in all cardiovascular events and a 57% reduction in the risk of nonfatal MI, stroke, or death from CVD.31

There has not been a large, long-term, controlled study showing decreases in macrovascular disease event rates from improved glycemic control in type 2 diabetes. Modification of other elements of the metabolic syndrome, however, has been shown to very significantly decrease the risk of cardiovascular events in numerous studies. Blood pressure lowering in patients with type 2 diabetes has been associated with decreased cardiovascular events and mortality. The UKPDS was among the first and most prominent studies demonstrating a reduc-
tion in macrovascular disease with treatment of hypertension in type 2 diabetes.32,33

There is additional benefit to blood pressure lowering with ACE inhibitors or ARBs. Blockade of the renin angiotensin system using either an ACE inhibitor or an ARB reduces cardiovascular endpoints more than other antihypertensive agents.13,20,34 It should be noted that use of ACE inhibitors and ARBs also may help slow progression of diabetic microvascular kidney disease (as described above). Multiple drug therapy, however, is generally required to control hypertension in patients with type 2 diabetes.

Another target of therapy is blood lipid concentration. Numerous studies have shown decreased risk in macrovascular disease in patients with diabetes who are treated with lipid-lowering agents, especially statins. These drugs are effective for both primary and secondary prevention of CVD, but patients with diabetes and preexisting CVD may receive the highest benefit from treatment. Although reviewing all relevant studies is beyond the scope of this article, it should be noted that the beneficial effects of lipid and blood pressure lowering are relatively well proven and likely also extend to patients with type 1 diabetes.

In addition to statin therapy, fibrates acid derivatives have beneficial effects. They raise HDL levels and lower triglyceride concentrations and have been shown to decrease the risk of MI in patients with diabetes in the Veterans Affairs High-Density Lipoprotein Cholesterol Intervention Trial.20,26,35–39

**Practice Recommendations**

Patients with type 1 diabetes of > 5 years' duration should have annual screening for microalbuminuria, and all patients with type 2 diabetes should undergo such screening at the time of diagnosis and annually thereafter. All patients with diabetes should have serum creatinine measurement performed annually. Patients with microalbuminuria or macroalbuminuria should be treated with an ACE inhibitor or ARB unless they are pregnant or cannot tolerate the medication. Patients who cannot tolerate one of these medications may be able to tolerate the other. Potassium should be monitored in patients on such therapy. Patients with a GFR < 60 ml/minute or with uncontrolled hypertension or hyperkalemia may benefit from referral to a nephrologist.15,40

Patients with type 1 diabetes should receive a comprehensive eye examination and dilation within 3–5 years after the onset of diabetes. Patients with type 2 diabetes should undergo such screening at the time of diagnosis. Patients should strive for optimal glucose and blood pressure control to decrease the likelihood of developing progression of diabetic retinopathy.15,40

All patients with diabetes should undergo screening for distal symmetric polyneuropathy at the time of diagnosis and annually thereafter. Atypical features may prompt electrophysiological testing or testing for other causes of peripheral neuropathy. Patients who experience peripheral neuropathy should begin appropriate foot self-care, including wearing special footwear to decrease their risk of ulceration. They may also require referral for podiatric care. Screening for autonomic neuropathy should take place at the time of diagnosis in type 2 diabetes and beginning 5 years after the diagnosis of type 1 diabetes. Medication to control the symptoms of painful peripheral neuropathy may be effective in improving quality of life in patients but do not appear to alter the natural course of the disease. For this reason, patients and physicians should continue to strive for the best possible glycemic control.

In light of the above strong evidence linking diabetes and CVD and to control and prevent the microvascular complications of diabetes, the ADA has issued practice recommendations regarding the prevention and management of diabetes complications.

Blood pressure should be measured routinely. The goal blood pressure is < 130/80 mmHg. Patients with a blood pressure ≥ 140/90 mmHg should be treated with drug therapy in addition to diet and lifestyle modification. Patients with a blood pressure of 130–139/80–89 mmHg may attempt a trial of lifestyle and behavioral therapy for 3 months and then receive pharmacological therapy if their goal blood pressure is not achieved. Initial drug therapy should be with a drug shown to decrease CVD risk, but all patients with diabetes and hypertension should receive an ACE inhibitor or ARB in their antihypertensive regimen.15,40

Lipid testing should be performed in adult patients with diabetes at least annually. Lipid goals for adults with diabetes should be an LDL of < 100 mg/dl (or < 70 mg/dl in patients with overt CVD), HDL > 50 mg/dl, and fasting triglycerides < 150 mg/dl.

All patients with diabetes should be encouraged to limit consumption of saturated fat, *trans* fat, and cholesterol. Statin therapy to lower LDL by 30–40% regardless of baseline is recommended to decrease the risk of CVD in patients > 40 years of age. Patients < 40 years of age may also be considered for therapy. In individuals with overt CVD, special attention should be paid to treatment to lower triglycerides or raise HDL. Combination therapy with a statin plus other drugs, such as fibrates or niacin, may be necessary.
to achieve ideal lipid control, but patients should be monitored closely for possible adverse reactions of therapy.\textsuperscript{15,40}

Aspirin therapy (75–162 mg/day) is indicated in secondary prevention of CVD and should be used in patients with diabetes who are > 40 years of age and in those who are 30–40 years of age if other risk factors are present. Patients < 21 years of age should not receive aspirin therapy because of the risk of Reye’s syndrome. Patients who cannot tolerate aspirin therapy because of allergy or adverse reaction may be considered for other antiplatelet agents.\textsuperscript{15,40}

In addition to the above pharmacological recommendations, patients with diabetes should be encouraged to not begin smoking or to stop smoking to decrease their risk of CVD and benefit their health in other ways. It should also be noted that statins, ACE inhibitors, and ARBs are strongly contraindicated in pregnancy.

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