Review Article

Fat and Muscle Component of Body Mass Index (BMI) : Relation with Hyperinsulinemia

RD Lele*

Abstract
Currently there is tremendous interest in obesity and its harmful consequences. Height, weight and body mass index (BMI) along with waist girth are routinely used parameters. One snag in the interpretation of BMI > 25 as a measure of obesity is the assumption that the increase is mainly due to fat. This review emphasizes the importance of assessing the muscle component of BMI (by simple somatoscopy or somatotyping). 75 percent of Indian T2DM patients have a normal or low BMI, only 25 percent have BMI > 25, wherein muscle mass also contributes as well as fat. Hyperinsulinemia is anabolic to both fat and muscle. Since skeletal muscle is a primary site of insulin resistance, greater the muscle mass, greater the importance of physical exercise to overcome the insulin resistance and greater the importance of dietary supplement of n3-PUFA to optimize the phospholipid composition of the muscle membrane (increasing membrane fluidity and thereby permitting longer residence of GLUT-4 in the plasma membrane).
I propose three testable hypotheses :
(1) Brown fat (FDG-PET imaging) and UCP2 and UCP3 expression in muscle are positively correlated with ectomorphy and mesomorphy, and negatively correlated with endomorphy and obesity. BAT is absent in obese people.
(2) Indian T2DM patients with normal or low BMI have increased UCP2 and UCP3 expression in their muscle, as well as increased high molecular weight adiponectin which promote fatty acid oxidation and prevent obesity.
(3) Indian T2DM with BMI > 25 and obesity have dysfunction of UCP2 and UCP3. They have high leptin with leptin resistance (induced by hyperinsulinemia) and low adiponectin. There is inverse relationship between adipose mass and adiponectin production. ©

INTRODUCTION
The harmful effects of obesity and its relationship to type 2 diabetes mellitus (T2DM) have been appreciated by clinicians at all times. The following comments in Charak Samhita (600BC) sound refreshingly contemporary :
“A person who is habituated to pampering his belly even when a previous meal has not been thoroughly digested; who is addicted to a habit of sleeping in the day or leading a sedentary life, who is averse to taking any sort of physical exercise ….. His lymph chyle is transformed into serum of sweet taste, which moves about within the body engendering the formation of fat which produced excessive stoutness ……. He suffers from thirst, ravenous appetite, inert feeling in the limbs …. he is likely to be affected by many diseases that invariably terminate in death….. due to the obstruction of the internal channels due to deposition of fat …..hence all things and conditions which foster the growth of abnormal fat should be carefully avoided”.
Currently there is worldwide concern about the growing epidemic of obesity and the consequent steep rise in T2DM expected over the next 20 years. Height, weight and body mass index (BMI) expressed as weight in kg. divided by height in meters squared are the routinely used parameters. BMI between 18-24 is taken as normal and BMI ≥ 25 is taken as overweight. The additional emphasis is on waist measurement and waist – hip ratio (WHR) as an independent parameter, especially in the Asian Indian population. An increased waist measurement at any level of BMI is an indicator

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of central or visceral obesity, phenotype of Insulin Resistance Syndrome & metabolic syndrome.

One snag in the interpretation of BMI > 25 as a measure of obesity is the assumption that the increase is due to excess fat, although it can be due to increased muscle mass as well. The aim of this article is to emphasize that (1) the muscle component of BMI in T2DM is totally neglected in our current thinking process, and (2) that muscle mass can be easily assessed and that (3) muscle mass is relevant as a primary site of insulin resistance and for the management of insulin resistance with regular physical exercise.

The statement applicable to western T2DM that 80 percent of them are obese does not apply to Asian Indian T2DM in whom less than 25% males and less than 47% females are overweight, but all of them have a significant muscle component (75% male and 50% female T2DM). Indian T2DM patients with normal or low BMI have increased visceral fat as indicated by increased waist girth.

Varieties of human physique: The monumental work on “Varieties of Human Physique”2 stimulated the study of the human physical constitution in clinical medicine3. The Atlas of Man4 facilitated the application of somatotyping by physical anthropometry5 to clinical disease states.6,7 A notable Indian contribution on Somatotyping and physique8 brought the awareness of this useful clinical tool to Indian clinicians and diabetologists. The strong muscle (mesomorphic) component in T2DM and Coronary Artery Disease (CAD) was recognized.9 This stimulated me to undertake somatotyping of over 600 T2DM patients.10 Since the present generation of clinicians seems to be unfamiliar with this subject, a brief recapulation of previous published data is worth while.

SOMATOTYPING

Somatotyping is an estimation of body build or physique. The physique is measured in terms of its shape and the three layers of the germ plate-endoderm, mesoderm and ectoderm, which form its basic components. The gut and the viscera are developed from the endoderm, and predominate in those with dominant endomorphy. The muscles and bones are developed from the mesoderm and these predominate in mesomorphy. The skin and nervous system are derived from the ectoderm and are well developed in predominant ectomorphy.

Somatotyping recognizes the continuous variation in the degree of development of these three components in different persons and even in different regions of the same body. Each physique consists of some degree of each component – 1 represents minimum and 7 the maximum, and 4 the mid-position of each component (Fig. 1). In a 3 digit representation, the first digit represents endomorphy, middle digit mesomorphy and the last digit ectomorphy.

The somatotyping of five regions – head and neck, thorax, upper limb, abdomen and lower limb – may show varying degrees of dysplasia or disproportionate development.

It is perfectly feasible to judge by inspection (Somatoscopy) the predominant primary component and the secondary component. In the clinical examination ten types of physiques can be recognized.

(1) endomorph-711. (2) mesomorph-171. (3) ectomorph-117. In these the main component has the rating of 7; other two components do not exceed rating of 2. (4) endomorphic mesomorph-142. (5) ectomorphic mesomorph-245. (6) ectomorphic endomorph254. (7) mesomorphic endomorph-651,551,552 (8) mesomorphic ectomorph-244. (9) endomorphic ectomorph-425 : in these the main component has the rating 5-6 and the other components’ rating 3-4. (10) Mid range-444 in whom all the 3 components lie between 3 and 4. Along with height and weight and WHR, somatoscopy should be included in the assessment of physique.

The rating of 1 to 7 can be given in terms of maleness and femaleness, with android and gynoid types at extreme ends (Fig. 2).

According to the distribution of fat and configuration of chest and pelvis (broad, narrow ) easily measured by a caliper, the obese subjects can be characterized as follows:

Fig 1 : Examples of extreme ectomorphs-117 Mesomorph (171) and endomorph 711. Most physiques fall in midrange 444 as shown in the scatter diagram.1 (Reprinted with permission from Dr. RD Lele)
(a) Gynoid: fat mainly in lower parts of the body: hips and thighs more than shoulders and neck. Hips broad; abdomen falling like an apron.

(b) Android: Well-developed muscles, apart from fat. Fat deposits mainly in upper half of the body. Hips narrow; thighs not fat.

(c) Mixed: a combination of gynoid and android

Somatotyping of patients with T2DM

During my tenure as Prof. of Medicine at the Govt. Medical College and Hospital at Nagpur (1963–1968), Dr. Wesley Dupertuis visited my department for a week. He showed me his landmark somatotyping study of 800 patients who had recovered from acute myocardial infarct at the Cleveland Clinic in USA, with a striking predominance of endomorphic mesomorphs (Fig. 3). The types of physique prone to "heart attacks" are shown in Fig. 4. Under his guidance, I performed somatotyping of 607 patients of T2DM registered with the Diabetic Clinic between July 1963 and December 1965 (421 males and 186 females). Fig. 5 gives the scattergram of height in meters and weight in kg. and Table I gives the BMI. Table II gives the somatotype of the patients. The data clearly shows that among the male diabetics 30% were thin, 45% were average weight and 24.5% were overweight. Further the data brought out the significant muscle component in 75% male T2DM and 50% of female T2DM. The importance of the muscle component lies in the fact that muscle (along with the liver) is the primary target of insulin resistance. Adipose tissue is highly sensitive to insulin hence obesity is the expected consequence of hyperinsulinemia. The adipokines produced by distended adipocytes (leptin, resistin and
abnormal levels (140 mg%) were tested with intravenous tolbutamide response to confirm T2DM (this was 1965 before the advent of RIA insulin).

There were no examples of hyperandroid or hypergynoid types. Out of 40 males, 33 were android (of whom 10 were detected to have T2DM); two were mixed (one diabetic) and 5 gynoid (none diabetic). Out of 20 females, 18 were gynoid (of whom 6 had diabetes), one android (no diabetes) and one mixed (no diabetes).

Hence we could not confirm Vague’s assertion that android obesity alone is significantly related to T2DM since our gynoid females had the same incidence of T2DM as our android males.

A noteworthy point is the strong mesomorphic component in overweight females with T2DM and CAD. (Table 3).

An interesting clinical observation was the delayed tendo-achilles jerk in all obese subjects which was not due to hypothyroidism.

**HYPERINSULINEMIA AND MUSCLE MASS**

Glucose uptake by muscle (cardiac and skeletal) and adipose tissue is insulin-dependent via recruitment of the GLUT4 (glucose transporter) from the interior of the cell to the plasma membrane. GLUT-4 is functionally associated with hexokinase.

| Table 1 : BMI in T2DM
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<tr>
<td></td>
<td>421 males</td>
<td>186 females</td>
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<tr>
<td>BMI &lt; 18</td>
<td>64 (15%)</td>
<td>9 (0.05%)</td>
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<tr>
<td>BMI 19 – 23</td>
<td>150 (35.6%)</td>
<td>31 (16.6%)</td>
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<tr>
<td>BMI 24 – 29</td>
<td>182 (43.2%)</td>
<td>91 (49%)</td>
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<tr>
<td>BMI 30 – 39</td>
<td>25 (6%)</td>
<td>49 (26.3%)</td>
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<tr>
<td>BMI &gt; 40</td>
<td>6 (3%)</td>
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| Table 2 : Somatotyping of T2 DM
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<tr>
<td></td>
<td>421 Males</td>
</tr>
<tr>
<td>1. Endomorphs</td>
<td>105 (25%)</td>
</tr>
<tr>
<td>2. Mesomorphic endomorphic</td>
<td>98 (23%)</td>
</tr>
<tr>
<td>3. Endomorphic mesomorphs</td>
<td>42 (10%)</td>
</tr>
<tr>
<td>4. Mesomorphs</td>
<td>88 (21%)</td>
</tr>
<tr>
<td>5. Mid-rangers &amp; ectomorphs</td>
<td>88 (21%)</td>
</tr>
<tr>
<td>Total</td>
<td>421 (100%)</td>
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Table 3 : Asymptomatic T2 DM & CAD in obese subjects

<table>
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<tr>
<th>Incidence of “silent” diabetes and coronary heart disease in obese subjects (40 males, 20 females)</th>
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<tr>
<td>Sex</td>
</tr>
<tr>
<td>Mesomorph</td>
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<tr>
<td>Diabetic</td>
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<td></td>
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<tr>
<td>CAD</td>
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Only in 2 males and 3 females silent T2DM and CAD coexisted.

Fig 5: Height-weight distribution of 607 adult T2DM: 421 males, 186 females. (Reprinted with permission from Dr. RD Lele)

Fig 6: FDG-PET image anterior posterior and cross-sectional pelvis showing symmetrical distribution of brown adipose tissue (BAT) in the neck, shoulders, paraspinal regions, mediastinum, abdomen and pelvis. Fusion of PET image with CT gives precise anatomic localization of BAT. This can be misinterpreted as infection or cancer. (Reprinted with permission from Dr. RD Lele)

**TNFα** contribute to secondary insulin resistance, which comes on the scene later.

**Android and Gynoid obesity and T2 DM**

Jean Vague (1958) had asserted that effects of android obesity are metabolic (T2 DM, CAD, HT) while effects of gynoid obesity are mechanical (flat feet, osteoarthritis, varicose veins, restricted ventilation etc.). To scrutinize this proposition we selected 60 obese healthy subjects at random (40 males 20 females) aged 20 – 60 from the middle class population of the city of Nagpur. They underwent a thorough physical examination, BP, resting and exercise ECG and 2 hour post meal blood sugar. Those with suspicious levels (120 – 140 mg%) or
In contrast, there is no direct effect of insulin on glucose uptake by the hepatocyte via GLUT-2 (which is functionally associated with glucokinase, an enzyme induced by insulin), or the brain, kidney, placenta and erythrocytes (GLUT1 and GLUT-3) or the small intestine (GLUT-2, GLUT-5, SGLUT-1).

Insulin also promotes the entry of aminoacids into muscle and their incorporation into protein, an effect independent of the action of insulin on glucose entry. Insulin stimulates protein synthesis and retards degradation. The effect of insulin on general protein synthesis in skeletal and cardiac muscle and in liver are thought to be exerted at the level of the mRNA translation. Insulin stimulates the proliferation of a number of cells in culture and is involved in the regulation of growth in vivo. In cultured fibroblasts insulin is a potent stimulator of C-fos and C-myc, similar to IGF-1, IGF-2, PDGF, EGF. Pro-insulin has less than 5% metabolic activity of insulin, but 50% activity in growth-stimulating activity (proliferation and differentiation) (mRNA synthesis and DNA synthesis).

Regulation of mRNA synthesis of more than 100 proteins are affected in the liver, adipose tissue, skeletal and cardiac muscle, under the stimulus of insulin.

We have shown a positive correlation between insulin, proinsulin and leptin to BMI. Since leptin is a marker of adipose mass it is easy to assess the adipose increased in BMI > 25, but there is no biochemical marker for muscle mass increase, for which somatotyping is very suitable. We can postulate that hyperinsulinemia is anabolic for both adipose tissue and muscle, as suggested by the significant association of T2DM, CAD and HT with mesomorphic endomorphs and endomorphic mesomorphs (Fig. 3). The increased abdominal girth in these subjects can be appreciated from Fig. 4, indicative of visceral obesity.

A comparative study of 40 women with polycystic ovary syndrome (PCOS) with metabolic syndrome (MBS) and 60 women with PCOS without MBS, showed that the increased BMI in PCOS and MBS was not due to adipose tissue but presumably due to higher muscle component (due higher levels of serum free testosterone and lower levels of serum SHBC) than women with PCOS without MBS. PCOS with MBS had higher prevalence of acanthosis nigricans suggestive of more severe insulin resistance, and increased risk for cardiovascular disease.13

Music is the largest tissue in the human body (less than 25 per cent at birth, more than 40 percent in young adult and somewhat less than 30 per cent in the aged). In humans skeletal muscle protein is the major non-fat source of stored energy. This explains the very large losses of muscle mass, resulting from prolonged caloric under nutrition. Mechanism of insulin’s anabolic effect on muscle has been studied by Chow LS et al (2006).14

**Thermogenesis: Brown Fat, Muscle and Uncoupling Enzymes**

Brown adipose tissue (BAT) and skeletal muscle are important sites of non-shivering thermogenesis. Non-exercise activity thermogenesis (NEAT) occurs in activities of daily living, fidgeting, spontaneous muscle contractions and maintenance of posture. Till recently there was no information about the presence and distribution of brown fat in adult humans. In new born babies brown fat cells are found in the neck areas helping their tiny bodies generate heat. Brown fat cells largely disappear by adulthood, but their precursors still remain lodged in white adipose tissue (WAT). Brown adipose tissue is characterized by a well developed blood supply, rich sympathetic innervation with high β3 adreno-receptor expression and a high content of mitochondria and cytochromes but low activity of ATP synthase. The proton gradient normally present across the inner mitochondrial membrane of coupled mitochondria is continually dissipated in brown adipose tissue by a thermogenic uncoupling protein thermogenin, which acts as a proton conducting pathway through the membrane. Due to uncoupling of oxidation and phosphorylation much heat is produced but little free energy is trapped in ATP (something similar to thyrotoxicosis) in the mitochondria in BAT, WAT and muscle. UCP1 is exclusively expressed in BAT. UCP2 is expressed in BAT, WAT and muscle. UCP2 locus on human chromosome 11 is linked to obesity and hyperinsulinism.15 UCP3 is expressed in skeletal muscle, a homologue of UCP1.16 Diet induced thermogenesis may account for the observation that some lucky individuals “eat a lot but do not get fat”. It is noteworthy that brown adipose tissue is reduced or absent in obese people. Transgenic mice with reduced BAT are obese indicating the important role of BAT in energy expenditure. Transgenic mice which over express UCP3 have hyperphagia but still do not gain weight. The availability of FDG-PET now enables us to document the presence and distribution of brown adipose tissue in humans. In FDG-PET studies in cancer patients brown fat was located in a very small number in the mediastinum (paratracheal, paraesophageal, prevascular, pericardial) and in the neck, thorax and abdomen. (Fig. 6). In thyrotoxicosis there is increased interscapular fat pad weight, its triacylglycerol content and DHA content.

Dysfunction of UCP3 reduces thermogenic capacity, alters energy homeostasis and promotes fat deposition. The C55 promoter polymorphism in UCP3 in South Indian women increases visceral fat deposition.17 There is inverse relationship between adipose mass and adiponectin production. Expression of UCP-1 in skeletal muscle decreases muscle energy efficiency and affects thermoregulation and substrate oxidation.19 Uncoupling proteins provide new clues for causation of obesity.20
Insulin in genesis of BAT: How insulin affects the conversion of preadipocytes into mature brown adipocytes is not known. Scientists at Joslin Diabetes Centre and Children’s Hospital Boston have discovered a group of genes that govern the genesis of calorie-burning brown fat cells. In Knockout cell lines of brown preadipocytes that lacked insulin receptor substrates (IRS-1) the precursors failed to develop into mature brown fat cells. Addition of IRS-1 into the knockout cells restored the ability to differentiate into brown fat cells. Reducing the level of a protein called necdin is essential for precursor to give rise to brown fat cells. This discovery may lead to new ways to treat obesity.21 Targeted deletion of insulin receptors in adipose tissue protects against obesity, apparently by increasing energy expenditure. Metabolic activity of BAT is increased by a central action of leptin via the sympathetic nervous system which heavily innervates BAT. β3 adrenergic agonists stimulate BAT and protect against obesity and T2 DM. A mutation in human β3 ADReceptor is associated with increased risk of insulin resistance and obesity in certain populations. Cinti A (2006) has discussed the role of BAT in human obesity.22

**Skeletal Muscle Membrane Phospholipids: Role of Dietary PUFAs**

The fatty acid composition of skeletal muscle membrane phospholipid is altered by n-3 PUFA, increasing the fluidity, thereby permitting prolonged residence of GLUT-4 in the plasma membrane.23 Breast milk contains n-6 and n-3 PUFA in right proportion, and breadfed infants have a muscle membrane fatty acid composition, similar to insulin-resistant adults. Mothers with insulin resistance have children with less EPA and DHA in their muscle membrane and at increased risk for development of insulin resistance.24,25 Pima Indians have reduced capacity to incorporate n-3 PUFA into muscle membrane. There may be genetic differences in the incorporation of n3 PUFA in the lipid membrane. The activity of D6 and D5 desaturase, enzymes required for the synthesis of AA from LA and DHA from ALA is impaired in T2DM.

Dietary PUFAs function as fuel partitions in that they direct glucose towards glycogen storage, and direct fatty acids away from triglyceride synthesis and storage, and towards fatty acids oxidation, enhance thermogenesis and thereby reduce fat deposition. This is achieved via upregulating the transcription of the mitochondrial UCP-3 and inducing genes encoding proteins involved in fatty acid oxidation (eg. carnitine palmitoyl transferase and acyl CoA oxidase), while simultaneously down-regulating the transcription of the genes coding proteins eg. fatty acid synthase involved in lipid synthesis.26 UCP2 and UCP-3 appear to be induced by dietary fat, particularly n-3 PUFA (EPA and DHA), which induce fatty acid oxidation in both liver and skeletal muscle, suppress hepatic lipogenesis and reduce hepatic triglyceride output.

Peroxisomal fatty acid oxidation and mitochondrial uncoupling of oxidation and phosphorylation are both thermogenic. Enzymes of peroxisomal fatty acid oxidation in both liver and muscle are induced two to three fold by dietary fish oil rich in 20-22 c n3 PUFA and by PPARα specific ligands.

Although the amount of Peroxisomal fatty acid oxidation in skeletal muscle is unknown, the large size of the muscle mass, and a two fold increase in the peroxisomal oxidative capacity of skeletal muscle suggests that the peroxisome could be a significant site of fatty acid oxidation and diet-induced thermogenesis. N3 PUFA in diet induce thermogenic pathways and reduce fat deposition by 25 per cent. Interestingly, enhancement of fatty acid oxidation and thermogenesis by dietary PUFA is associated with an improvement in the glucose uptake and insulin sensitivity.

Ingestion of PPARα ligand is accompanied by an increase in expression of skeletal muscle UCP3 and a decrease in hepatic expression SREBP-1 and fatty acid synthase. SREBP-1 over-expression in the liver is associated with high rates of de novo fatty acid bio synthesis and a several-fold induction in the transcription of lipogenic genes. PPARα knock out mice, as they grow older, develop insulin resistance and body fat gain. Agents that induce D6 and D5 desaturase pathways appear to improve insulin sensitivity. PPARγ and PPARδ ligands may potentially enrich the membrane phospholipid with 20 : 5 and 22 : 6 n-3 and thereby explain how these ligands improve skeletal muscle glucose uptake. The RBC membrane is a prototype of all cell plasma membranes including endothelial cells. Decreased DHA in RBC membrane (2.98 ± 2.18) compared to normal (4.18 ± 1.42) affects receptor binding and enzyme activation. Membrane protein CD36 (fatty acid translocase which is a facilitator of long chain fatty acids) is deficient in a rat model of human metabolic syndrome.27

**Role of Leptin and adiponectin**

Leptin regulates food intake by central action and it stimulates fatty acid oxidation through AMP kinase activation in the adipose tissue. Hyperinsulinemia on the one hand promotes leptin production but on the other hand promotes Leptin Resistance at the AMPK level, as seen in obese T2DM where high insulin and leptin levels co-exist.

Adiponectin also stimulates phosphorylation of acetyl Co A Carboxylase and oxidation of FFAs. There is inverse relationship between adipose mass and adiponectin production. Obese Indian T2DM patients
have low adiponectin levels.12

**Muscle As A Target Of Insulin Resistance**

Glucose transport via GLUT-4 is a critical rate-controlling step for glucose uptake by muscle and insulin-stimulated glycogen synthesis in muscle. Glycogenin is a protein primer for glycogen synthesis and is a determinant of maximum glycogen storage capacity. In T2DM there is a marked decrease in muscle glycogen synthesis (as shown by C-13 MRS and C-13 glucose-1). This defect is also seen in 1st degree relatives and off-springs of T2DM patients.

TNFα inhibits insulin receptor tyrosine kinase activity in adipocytes and muscle (but not liver) via serine phosphorylation of IRS-1 which in this modified form inhibits insulin receptor tyrosine kinase activity and signal transduction.

Inhibition of glucose transport into muscle may be a consequence of deceased IRS-1_PI_3K activity. Neutralization of TNFα by specific antibodies improves insulin-stimulated glucose uptake in muscle.

Increased fat accumulation in muscle (similar to that in the liver) is seen in elderly lean and healthy subjects due to 40% reduction in mitochondrial oxidative phosphorylation. Out of the set of genes involved in oxidative phosphorylation (OXPHOs), a small subset is coregulated (OXPHOs-CR), whose expression is down-regulated (~20%) in muscles of patients with T2DM as well as IGT. This is clinically manifest by early muscle fatigue experienced by them. This down-regulation precedes the onset of hyperglycaemia and is not a consequence of it. Modulation of OXPHOS-CR activity might be a suitable target for prevention and treatment of IR and T2DM.

Elevated plasma FFAs act through inhibition of muscle glucose transport / phosphorylation to G6 phosphate through hexokinase.

**Three Testable Hypotheses**

Based on the review so far, I propose the following three testable hypotheses:

1. Brown fat (FDG-PET imaging) and UCP2 and UCP3 expression in muscle are positively correlated with ectomorphy and mesomorphy, and negatively correlated with endomorphy and obesity. BAT is absent in obese people.

2. Indian T2DM patients with normal or low BMI have visceral obesity (increased waist girth and high visceral fat area (HVFA) at the level of 4th lumbar vertebra on CT which determines post-prandial lipidemic response. They have increased expression of UCP2 and UCP3 expression in their muscle, as well as increased high molecular weight adiponectin, which promote FFA oxidation and prevent obesity.

3. Obese Indian T2DM patients have dysfunction of muscle UCP2 and UCP3, which promotes fat deposition. Although they have high leptin levels, they have leptin resistance due to hyperinsulinemia at the molecular level of AMPKinase. They also have low adiponectin. There is inverse relationship between adipose mass and adiponectin production.

**Importance Of Physical Exercise**

Skeletal muscle contains 2 types of fibres: type I (slow twitch) fibre are red because they contain myoglobin (a reservoir for oxygen) and high number of mitochondria; they maintain relatively sustained contraction (such as maintaining of posture) and their metabolism is aerobic.

Type II (fast twitch) fibres lack myoglobin (hence white) and have very few mitochondria, exhibit short duration of contraction and derive their energy from phosphocreatine and anerobic glycolysis of glycogen.

Athletes training for marathons have increase in the number of type 1 fibres in certain leg muscles, whereas 100 meter sprinters have an increase in the number of type 2 fibres.

“Preloading” with glucose is used by some long distance runners to build up stores of glycogen. Free fatty acids in plasma are a major source of energy particularly under marathon conditions and in prolonged starvation.

Impact of exercise training on insulin sensitivity, physical fitness and muscle oxidative capacity in first degree relatives of T2DM patients has been studied. Exercise activates a series of signal transduction cascades controlling glucose uptake, glycogen synthesis, gene expression and protein synthesis.

In human skeletal muscle exercise results in increased mitogen-activated protein kinase (MAPK) activity and the activation of down-stream targets of MAPK Exercise increases GLUT-4 and hexokinase II and glycogenin gene expression in human skeletal muscle. GLUT-4 gene and protein expression are upregulated very early after exercise and remain elevated for several hours during recovery. In humans, one hour of moderate intensity exercise increases Hexokinase II transcription and mRNA and protein levels up to 3 hours after the end of exercise. Increased glycogenin gene expression results in increased glycogen resynthesis during recovery from exercise.

Therefore, greater the muscle mass, greater the importance of regular exercise to overcome insulin resistance in muscle, and dietary supplementation of n3 PUFAs to optimize muscle membrane phospholipid composition.
REFERENCES

7. Tanner JM. Somatotype and medicine.