ENZYMES OF DIGESTION

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**Keywords:** Digestion, amylase, lipase, pepsin, endopeptidases, peptidases

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**Summary**

The enzymes of digestion are produced and secreted from almost all parts of the digestive system: salivary glands, lingual glands, stomach, pancreas, liver and intestinal mucosa. Often the final steps of digestion take place in the villi of enterocytes. These enzymes are almost all hydrolases. The digestion of carbohydrates begins in mouth by the salivary amylase and continues in the small intestine by pancreatic amylase and the intestinal and mucosal oligo- and disaccharidases. The enzymes involved in fat
digested are the lingual, gastric, pancreatic and intestinal lipases. However, the main
digestion of fats occurs in the small intestine by pancreatic lipase with the contribution
of bile acids. The digestion of proteins begins in the stomach by pepsins, the active form
of pepsinogens which is secreted from the chief cells of the gastric glands. The
proteolytic enzymes of the pancreas, i.e. trypsin, chymotrypsin and
carboxyprotepeptidase, which are also secreted in inactive forms, continue protein
digestion. The end products of protein digestion are amino acids, produced by the action
of intestinal and mucosal dipeptidases.

1. Introduction

Preparation of foods contributes to their digestibility. Foods contain several autolytic
enzymes. Many foods are fermented i.e. bacterial enzymes contribute to the digestibility
of their components. Cooking denatures proteins, breaks cell walls, etc. and again the
digestibility is promoted.

Almost all the enzymes of digestion are hydrolases. They are secreted by the salivary
glands and gastric glands, pancreas and liver and the intestinal enterocytes. The actions
of the digestive enzymes are similar to those of the lysosomal enzymes of the cells,
except that they have different pH optima. Lysosomal enzymes are mostly active at
acidic pH, whereas the digestive enzymes except pepsins have their activity optima at a
pH of 6.5 to 7.5.

Many of the digestive enzymes have trivial names, such as pepsin and trypsin, since
they were the first enzymes to be discovered before the systematic nomenclature was
developed.

Although the basic principles of digestion are the same in most species we humans are
interested, there are still significant differences between e.g. herbivoric and omnivoric
species compared with predators, which have much shorter guts (see also Alimentary
Systems in Some Homeothermic Vertebrates).

2. Hydrolysis

If an organic molecule is split by addition of water, the reaction is called hydrolysis.
Three major types of food, carbohydrates, lipids and proteins, are all digested by
hydrolysis, but the enzymes catalyzing the reactions are different in each case.

Almost all the carbohydrates of the human diet are large polysaccharides or
disaccharides, and they are combinations of monosaccharides bound to one another by
condensation. The first stage of this reaction is the removal of a hydrogen ion from a
monosaccharide and then a hydroxyl ion from another one. The two monosaccharides
are then combined with each other at the sites of removal, and the hydrogen and
hydroxyl ions combine to form water. When the carbohydrates are digested back into
monosaccharides, specific enzymes return the hydrogen and hydroxyl ions to the
polysaccharides and thereby separate the monosaccharides from each other.
The majority of fats in the diet consist of triglycerides (neutral fats), which are combinations of three fatty acid molecules condensed with a single glycerol molecule. Phospholipids consist of a phosphate and two fatty acid molecules. Cholesterol esters consist of a cholesterol and one fatty acid molecule. In the digestion of triglycerides, the fat-digesting enzymes return water to the triglyceride molecule, thereby splitting the fatty acid molecules away from the glycerol.

Finally, proteins are composed of amino acids bound together by peptide linkages. In this linkage, a hydroxyl ion is removed from one amino acid and a hydrogen ion is removed from the next one in condensation. In their digestion, the proteolytic enzymes return water to the peptide bonds to release the constituent amino acids.

### 3. Enzymes of Digestion According to their Sites of Secretion

Table 1 listed the sources, activators, substrates, actions and end products of the enzymes of digestion.

<table>
<thead>
<tr>
<th>Source</th>
<th>Enzyme</th>
<th>Activator</th>
<th>Substrat</th>
<th>Action</th>
<th>Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salivary glands</td>
<td>Salivary α-amylase (ptyalin)</td>
<td>Cl</td>
<td>Starch</td>
<td>Hydrolyzes 1-4α linkages</td>
<td>α-Limit dextrins, maltorose, and maltose</td>
</tr>
<tr>
<td>Lingual glands</td>
<td>Lingual lipase</td>
<td>HCl</td>
<td>Triglycerides</td>
<td>Fatty acids and 1,2-diacylglycerols</td>
<td></td>
</tr>
<tr>
<td>Stomach</td>
<td>Pepsins (pepsinogens)</td>
<td>HCl</td>
<td>Proteins and polypeptides</td>
<td>Cleave peptide bonds adjacent to aromatic amino acids</td>
<td>Proteoses, peptons and polypeptides</td>
</tr>
<tr>
<td></td>
<td>Gastric lipase</td>
<td>HCl</td>
<td>Triglycerides</td>
<td>Lipolysis</td>
<td>Fatty acids and glycerol</td>
</tr>
<tr>
<td>Pancreas</td>
<td>Endopptidases Trypsin (Trypsinogen)</td>
<td>Enterokinase and trypsin</td>
<td>Proteins and polypeptides</td>
<td>Cleaves peptide bonds adjacent to arginine or lysine</td>
<td>Polypeptides and amino acids</td>
</tr>
<tr>
<td></td>
<td>Chymotrypsins (chymotrypsinogens)</td>
<td>Trypsin</td>
<td>Proteins and polypeptides</td>
<td>Cleaves peptide bonds adjacent to arginine or lysine</td>
<td>Polypeptides and amino acids</td>
</tr>
<tr>
<td></td>
<td>Elastase (proelastase)</td>
<td>Trypsin</td>
<td>Elastin, some other proteins</td>
<td>Cleaves peptide bonds adjacent to aliphatic amino acid</td>
<td>Polypeptides and amino acids</td>
</tr>
<tr>
<td></td>
<td>Carboxypeptidase A (procarboxypeptidase A)</td>
<td>Trypsin</td>
<td>Proteins and polypeptides</td>
<td>Cleaves carboxy-terminal amino acids that have aromatic or branched</td>
<td>Polypeptides and amino acids</td>
</tr>
</tbody>
</table>
### Table 1. The sources, activators, substrates, actions and end products of the enzymes of digestion.

<table>
<thead>
<tr>
<th>Enzyme (or enzyme complex)</th>
<th>Source</th>
<th>Activator</th>
<th>Substrate</th>
<th>Action</th>
<th>End Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carboxypeptidase B (procarboxypeptidase B)</td>
<td>Trypsin</td>
<td>Proteins and polypeptides</td>
<td>Cleaves carboxy-terminal amino acids that have basic side chains</td>
<td>Polypeptides and amino acids</td>
<td></td>
</tr>
<tr>
<td>Colipase (procolipase)</td>
<td>Trypsin</td>
<td>Fat droplets</td>
<td>Facilitates exposure of active site of pancreatic lipase</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pancreatic lipase</td>
<td>...</td>
<td>Triglycerides</td>
<td>Lipolysis</td>
<td>Monoglycerides and fatty acids</td>
<td></td>
</tr>
<tr>
<td>Cholesteryl ester hydrolase</td>
<td>...</td>
<td>Cholesteryl esters</td>
<td></td>
<td>Cholesterol and fatty acids</td>
<td></td>
</tr>
<tr>
<td>Pancreatic α-amylase</td>
<td>CI</td>
<td>Starch</td>
<td>Hydrolyzes 1:4α linkages</td>
<td>α-Limit dextrins, maltotriose, and maltose</td>
<td></td>
</tr>
<tr>
<td>Ribonuclease</td>
<td>...</td>
<td>RNA</td>
<td></td>
<td>Nucleotides</td>
<td></td>
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<tr>
<td>Deoxyribonuclease</td>
<td>...</td>
<td>DNA</td>
<td></td>
<td>Nucleotides</td>
<td></td>
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<tr>
<td>Phospholipase A₂ (prophospholipase A₂)</td>
<td>Trypsin</td>
<td>Phospholipids</td>
<td></td>
<td>Fatty acids, lysophospholipids</td>
<td></td>
</tr>
<tr>
<td>Intestinal mucosa</td>
<td>Dipeptidase</td>
<td>Dipeptides</td>
<td>Amino acids</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maltase</td>
<td>...</td>
<td>Maltose, maltotriose</td>
<td></td>
<td>Glucose</td>
<td></td>
</tr>
<tr>
<td>Lactase</td>
<td>...</td>
<td>Lactose</td>
<td>Galactose and glucose</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sucrase</td>
<td>...</td>
<td>Sucrose</td>
<td>Fructose and glucose</td>
<td></td>
<td></td>
</tr>
<tr>
<td>α-Limited dextrinase</td>
<td>...</td>
<td>A-Limit dextrins</td>
<td></td>
<td>Glucose</td>
<td></td>
</tr>
<tr>
<td>Nuclease and related enzymes</td>
<td>...</td>
<td>Nucleic acids</td>
<td>Pentoses and purine and pyrimidine bases</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cytoplasm of mucosal cells</td>
<td>Various peptidases</td>
<td>Di, tri, and tetrapeptides</td>
<td>Amino acids</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3.1. Ptyalin (α-amylase)

The only enzyme having physiological significance in saliva is ptyalin (α-amylase). It is secreted mainly by the parotid glands. Ptyalin starts the digestion of carbohydrates such as plant starch and muscle glycogen. Starch is our main source of energy. Salivary amylase can hydrolyze starch into the disaccharide maltose and other small polymers of glucose such as maltotriose and α-limit dextrins that originate from the branch points of the starch molecule. However, because ptyalin can only act on the food for a short period, oral digestion has limited significance. Carbohydrate digestion continues in stomach for a while. Explanation for the continuation of ptyalin action is slow penetration of hydrochloric acid into the swallowed bolus The optimal pH of salivary
Amylase is 6.7. When a food bolus enters the stomach, its action is inhibited by the acidic gastric juice, which has a pH of 4.0 or less. The salivary α-amylase hydrolyzes 1:4 α linkages but not 1:6 α linkages—terminal 1:4 α linkages, and the 1:4 α linkages next to branching points. Probably, not more than 5% of all the starches that are ingested become hydrolyzed within the mouth before the food is swallowed. Starch digestion by ptyalin continues in the corpus and fundus of the stomach for as long as an hour, and, therefore, as much as 30 to 40% of the starch may be hydrolyzed mainly to maltose before the food becomes mixed with the acidic gastric juice.

3.2. Lingual Lipase

The serous lingual glands (Ebner’s glands), on the dorsal surface of the tongue, secrete lingual lipase. As much as 30% of dietary triglyceride is digested in the stomach by the actions of lingual and gastric lipases together, producing fatty acids and 1,2-diacylglycerols. Lingual lipase appears to have little practical importance in lipid digestion. On the other hand, in premature infants in whom pancreatic lipase is insufficiently secreted or in children with congenital deficiency of pancreatic lipase, about half of dietary triacylglycerols can be digested and, therefore, absorbed, presumably due to the action of these lipases.

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Bibliography


Ganong W.F. (1999). Review of Medical Physiology, 781 pp. Connecticut: Appleton and Lange. [This is a medical physiology textbook, which is used in almost all countries.]
Guyton A.C., and Hall J.E. (2000). Textbook of Medical Physiology, 1064 pp. 10th edition. W. B. Saunders Company, Philadelphia. [This is a textbook, which is read in the almost all countries for medical physiology.]

Holden C. and Mace R. (1997). Human Biology, vol. 69, 605-628. Phyllogenetic analysis of the evolution of lactose digestion in adults. [High lactose digestion capacity in adults is common only in populations of European and circum-Mediterranean origin and is thought to be an evolutionary adaptation to millennia of drinking milk from domestic livestock.]


Vander A.J., Sherman J.H. and Luciano D.S. (2001). Human Physiology, the mechanisms of body function, 800 pp. Boston: McGraw-Hill, Inc. [This is a textbook, which is read in the almost all countries for medical physiology.]

Biographical Sketches

Prof. Dr. Senol DANE was born in 1963, in Konya, Turkey. He graduated from Ege University, Medical Faculty, Izmir, Turkey, in 1986. He completed his specialization in Physiology in 1990 in Ataturk University, Medical Faculty. Currently, he is serving as a Professor of Physiology and head of the Physiology Department in the Medical Faculty of Ataturk University, Erzurum, Turkey. He is a member of the Turkish Physiological Society, Neuroscience Society of Turkey, International Brain Research Organisation and New York Academy of Sciences. He is married and the father of four children.

Dr Osmo Otto Päiviö Hänninen, DMS, Ph.D., Professor of Physiology, Chairman of the Department, University of Kuopio, Finland. Born 1939, Lahti, Finland. He studied at the University of Helsinki and the University of Turku, Finland, where he received his Master of Sciences (Biochemistry) in 1962, Licentiate of Medicine (MD) in 1964, Doctor of Medical Sciences (DMS) in 1966, and passed his dissertation in biochemistry for his Ph.D. in 1968. He has also studied genetics. He has been a specialist in sports medicine since 1986. He served as the Research Assistant of Professor K. Hartiala, 1962–4; Assistant of Physiology, 1964–5; Laborator of Physiology, 1966–7; Docent of Physiology, from 1967, and Associate Professor of Biochemistry, 1969–71, at the University of Turku; Acting Professor in the Planning Office, 1971–2; and from 1972, Professor of Physiology and Chairman of the Department of Physiology, University of Kuopio; Vice-President of the University of Kuopio, 1972–9; and President, University of Kuopio, 1981–4. Furthermore, he served as Visiting Professor of Physiology at Shanghai Medical University, China, 1991–2, and at Sun Yat Sen Medical University, Guangzhou, China, 1998–9; as Foreign Member of the Russian Academy of Natural Sciences, from 1994; and as Secretary General, International Council for Laboratory Animal Science, 1988–95. He was the President of Societas Physiologica Finlandiae, 1990–9, and has been President of the International Society for Pathophysiology and a Member of the Executive Committee since 1994, and the Treasurer of the International Union of Biological Sciences since 1997.

His special interests in research are:

1. - Biotransformation and adaptation to chemical loading, biomonitoring of toxicants, and comparative biochemical toxicology.

3. Ergonomics.

He has contributed 266 papers in refereed journals and seventy-two in proceedings, and written fifty-five reviews, and thirty books or book chapters. He serves on the editorial board of four international journals and is at present the European Journal Editor of *Pathophysiology*.

Of his post-graduate students (thirty-two in biotransformation, twenty-seven in muscle metabolism and physiology, and five others), twelve serve as professors in China, Finland, Greece, Sweden, and the United States.