

A black and white photograph showing various cuts of meat hanging from hooks in a shop window, with some herbs visible below.

# RED MEAT AND PROCESSED MEAT

VOLUME 114

This publication represents the views and expert  
opinions of an IARC Working Group on the  
Evaluation of Carcinogenic Risks to Humans,  
which met in Lyon, 6–13 October 2015

LYON, FRANCE - 2018

IARC MONOGRAPHS  
ON THE EVALUATION  
OF CARCINOGENIC RISKS  
TO HUMANS

International Agency for Research on Cancer



# CONTENTS

---

NOTE TO THE READER .....	1
LIST OF PARTICIPANTS .....	3
<b>PREAMBLE .....</b>	<b>9</b>
A. GENERAL PRINCIPLES AND PROCEDURES .....	9
1. Background .....	9
2. Objective and scope .....	10
3. Selection of agents for review .....	11
4. Data for the <i>Monographs</i> .....	12
5. Meeting participants .....	12
6. Working procedures .....	13
B. SCIENTIFIC REVIEW AND EVALUATION .....	14
1. Exposure data .....	15
2. Studies of cancer in humans .....	16
3. Studies of cancer in experimental animals .....	20
4. Mechanistic and other relevant data .....	23
5. Summary .....	26
6. Evaluation and rationale .....	27
References .....	31
<b>GENERAL REMARKS .....</b>	<b>33</b>
<b>1. EXPOSURE DATA .....</b>	<b>37</b>
1.1 Identification of the agents .....	37
1.1.1 Red meat .....	37
1.1.2 Offal .....	37
1.1.3 Processed meat .....	37

---

1.2 Meat composition .....	39
1.2.1 Red meat .....	39
1.2.2 Processed meat .....	44
1.2.3 Changes in meat composition due to cooking methods .....	47
1.3 Exposure via food intake .....	54
1.3.1 Data description .....	54
1.3.2 Results .....	55
1.4 Exposure assessment and biological markers .....	83
1.4.1 Questionnaires .....	83
1.4.2 Biological markers .....	90
1.5 Regulations and guidelines .....	92
1.5.1 Prevention of infectious disease .....	93
1.5.2 Prevention of contamination .....	93
References .....	94
<b>2. CANCER IN HUMANS .....</b>	<b>107</b>
2.1 General issues regarding the epidemiology of cancer and consumption of red meat and processed meat .....	107
2.1.1 Exposure definition .....	107
2.1.2 Sample size and the number of exposed cases .....	108
2.1.3 Study design .....	108
2.1.4 Exposure assessment tools .....	108
2.1.5 Adjustment for potential confounding factors .....	108
References .....	109
2.2 Cancer of the colorectum .....	111
2.2.1 Cohort studies .....	111
2.2.2 Case-control studies .....	125
2.2.3 Meta-analyses .....	142
References .....	239
2.3 Cancer of the stomach .....	249
2.3.1 Cohort studies .....	249
2.3.2 Case-control studies .....	251
2.3.3 Meta-analyses .....	252
References .....	278
2.4 Cancer of the pancreas .....	281
2.4.1 Cohort studies .....	281
2.4.2 Case-control studies .....	284
2.4.3 Meta-analyses .....	288
References .....	301

---

2.5 Cancer of the prostate .....	303
2.5.1 Cohort studies .....	303
2.5.2 Case-control studies .....	304
References .....	316
2.6 Cancer of the breast .....	319
2.6.1 Cohort studies .....	319
2.6.2 Case-control studies .....	326
References .....	336
2.7 Cancer of the lung .....	343
2.7.1 Cohort studies .....	343
2.7.2 Case-control studies .....	344
2.7.3 Meta-analyses .....	347
References .....	348
2.8 Cancer of the oesophagus .....	351
2.8.1 Cohort studies .....	351
2.8.2 Case-control studies .....	352
2.8.3 Meta-analyses .....	353
References .....	353
2.9 Other cancers .....	357
2.9.1 Non-Hodgkin lymphoma .....	357
2.9.2 Cancer of the liver (hepatocellular carcinoma) .....	364
2.9.3 Cancers of the gallbladder and biliary tract .....	366
2.9.4 Cancer of the testis .....	367
2.9.5 Cancer of the kidney .....	367
2.9.6 Cancer of the bladder .....	371
2.9.7 Cancer of the ovary .....	376
2.9.8 Cancer of the endometrium .....	379
2.9.9 Leukaemia .....	381
2.9.10 Cancer of the brain .....	383
2.9.11 Cancer of the breast in men .....	384
References .....	384
<b>3. CANCER IN EXPERIMENTAL ANIMALS .....</b>	<b>389</b>
3.1 Mouse .....	389
3.1.1 Red meat .....	389
3.1.2 Red meat with known carcinogens .....	392
3.2 Rat .....	392
3.2.1 Red meat .....	392
3.2.2 Red meat with known carcinogens .....	407
3.2.3 Red meat and/or processed meat with known carcinogens to give aberrant crypt foci and/or mucin-depleted foci .....	411

3.3 Haem iron .....	416
3.4 Overview of cancer bioassays for chemicals related to meat consumption .....	416
3.4.1 Heterocyclic aromatic amines .....	416
3.4.2 Polycyclic aromatic hydrocarbons .....	420
3.4.3 <i>N</i> -Nitroso compounds .....	421
3.4.4 Others .....	422
References .....	422
<b>4. MECHANISTIC AND OTHER RELEVANT DATA .....</b>	<b>427</b>
4.1 Digestion and metabolism .....	427
4.2 Mechanisms of carcinogenesis .....	428
4.2.1 Genetic and related effects .....	428
4.2.2 Oxidative stress .....	440
4.2.3 Alteration of cell proliferation and cell death .....	442
4.2.4 Other mechanisms of carcinogenesis .....	443
4.2.5 Other relevant data and potential indirect mediators .....	445
4.2.6 Studies of hemin and hemin chloride .....	445
4.3 Precancerous lesions .....	446
4.3.1 Precancerous colorectal lesions .....	446
4.3.2 Other precancerous lesions in exposed humans .....	451
4.4 Cancer susceptibility .....	451
4.4.1 Genetic polymorphisms .....	451
4.4.2 Microflora .....	454
4.5 Meat components potentially involved in carcinogenesis .....	455
4.5.1 Haem iron .....	455
4.5.2 Lipid oxidation products .....	458
4.5.3 Heterocyclic aromatic amines .....	461
4.5.4 Polycyclic aromatic hydrocarbons .....	464
4.5.5 <i>N</i> -Nitroso compounds .....	466
4.5.6 Interactions between NOCs, haem iron, and HAAs .....	470
4.5.7 Other components .....	471
References .....	472
<b>5. SUMMARY OF DATA REPORTED .....</b>	<b>491</b>
5.1 Exposure data .....	491
5.2 Human carcinogenicity data .....	492
5.2.1 Cancer of the colorectum .....	492
5.2.2 Cancer of the stomach .....	494
5.2.3 Cancer of the pancreas .....	494
5.2.4 Cancer of the prostate .....	494
5.2.5 Cancer of the breast .....	495
5.2.6 Cancer of the lung .....	496
5.2.7 Cancer of the oesophagus .....	496
5.2.8 Other cancers .....	496
5.3 Animal carcinogenicity data .....	496
5.4 Mechanistic and other relevant data .....	497

<b>6. EVALUATION .....</b>	<b>501</b>
6.1 Cancer in humans.....	501
6.2 Cancer in experimental animals.....	501
6.3 Overall evaluation .....	501
6.4 Rationale .....	501
<b>LIST OF ABBREVIATIONS .....</b>	<b>503</b>



## **NOTE TO THE READER**

---

The term ‘carcinogenic risk’ in the *IARC Monographs* series is taken to mean that an agent is capable of causing cancer. The *Monographs* evaluate cancer hazards, despite the historical presence of the word ‘risks’ in the title.

Inclusion of an agent in the *Monographs* does not imply that it is a carcinogen, only that the published data have been examined. Equally, the fact that an agent has not yet been evaluated in a *Monograph* does not mean that it is not carcinogenic. Similarly, identification of cancer sites with *sufficient evidence* or *limited evidence* in humans should not be viewed as precluding the possibility that an agent may cause cancer at other sites.

The evaluations of carcinogenic risk are made by international working groups of independent scientists and are qualitative in nature. No recommendation is given for regulation or legislation.

Anyone who is aware of published data that may alter the evaluation of the carcinogenic risk of an agent to humans is encouraged to make this information available to the Section of IARC Monographs, International Agency for Research on Cancer, 150 cours Albert Thomas, 69372 Lyon Cedex 08, France, in order that the agent may be considered for re-evaluation by a future Working Group.

Although every effort is made to prepare the *Monographs* as accurately as possible, mistakes may occur. Readers are requested to communicate any errors to the Section of IARC Monographs, so that corrections can be reported in future volumes.

