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Composition and retention of lipid nutrients in cooked ground beef relative to heat-transfer rates

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Abstract

This study documents the effects of different heat transfer kinetics on lipid nutrient composition in regular ground beef patties cooked using high (HHT) and low (LHT) heat transfer frying surfaces. Rate of heating from frying surfaces to ground beef patties was measured using iron-constantan thermocouples and related to the retention of beef pattie color, texture, total crude lipid content, fatty acid and cholesterol composition. Ground beef patties cooked for 1, 3 and 6 min using an HHT frying surface reached a higher ($P \leqslant 0.05$) internal temperature than on the LHT frying surface. This observation was associated with higher ($P \leqslant 0.05$) cook value and cook loss, and greater ($P \leqslant 0.05$) shear force, L^* color value and ΔE values. The fatty acid composition of the HHT cooked patties reflected a greater ($P \leqslant 0.05$) loss in monounsaturated fatty acids, than with patties cooked on the LHT surface. The two frying methods produced little effect on beef a^* and b^* color values, total crude lipid, or polyunsaturated fatty acid content. Cholesterol content of HHT patties was reduced ($P \leqslant 0.05$) relative to both uncooked patties and patties cooked with a LHT surface. These results indicate that heat conductivity of the cooking surface has an impact on the lipid composition of cooked ground beef patties.

Keywords: Heating rate; Ground beef; Color; Lipids; Cholesterol; Cook value

1. Introduction

Ground beef is widely consumed in Canada, with a *per capita* consumption reportedly increasing from 30.8 kg in 1993, to 32.2 kg in 1998 (Statistics Canada, 1998). Various studies have been conducted on ground beef to determine the effect of cooking method on color, texture and nutrient composition. In particular, sensory and nutrient losses, which have been reported to vary with cooking time and temperature (Janiki & Appledorf, 1974), may also be related to the thermal conductivity of the cooking surface. Prolonged cooking at high temperature causes protein denaturation and a decrease in water holding capacity of ground beef (Warris, 2000). Moreover, some cooking loss will also represent non-aqueous fluid, since the high temperature will liquefy lipid. For example, a study conducted by Ono, Berry, and Paroczay (1985) found that the ratio of unsaturated fatty acids to saturated fatty acids increased after cooking. Cannell, Savell, Smith, Cross, and St. John (1989) reported that most cooking methods result in a product containing higher palmitic acid and lower stearic and oleic acids. Pan-frying, in particular, produced a product with a higher final fat content than other cooking methods (Cannell et al., 1989). Cholesterol content of cooked patties has also been shown to be related to cooking method (Kregel, Prusa, & Hughes, 1986). The purpose of the present study was to determine the effect of different thermal conductivities of cooking surfaces on the organoleptic and lipid nutrient composition of pan-fried ground beef patties.

2. Materials and methods

2.1. Preparation of meat samples

Regular ground beef was purchased in a local supermarket (Superstore, Vancouver), and was formed into 100-g patties (8.5 cm in diameter, 1.5 cm in thickness) by hand.

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2.2. Cooking methods

Precooking temperatures of beef patties (known to affect cooking time) ranged from 5.6 to 7.3°C. Patties were cooked in a high heat conductivity (HHC) surface made from chrome-nickel surgical steel (diameter: 21.6 cm, area of bottom: 366.4 cm, weight: 2.05 kg) and a low heat conductivity (LHC) surface made from teflon-coated stainless steel (diameter: 21.7 cm, area of bottom: 369.84 cm, weight: 1.35 kg) at 100°C on a preheated electric burner (220.8°C) in the absence of oil. Patties were cooked to 3° of cook according to the following paridigm: 1° of cook for 1 min (30 s on each side), 2° of "doneness" for 3 min (1.5 min on each side) and 3° of "doneness" for 6 min (3 min on each side). Internal temperature of beef patties during cooking was measured using an iron-constantan thermocouple inserted into the centre of each patty and connected to a datalogger. Preliminary cooking trials were conducted to determine the heating rate, cooking time and temperature required to achieve the 3° of cook. These measurements were used to calculate cook value ($C = \Sigma 10^{(T-100)/z} \cdot t$), where C is the cook value in minutes; T is the temperature in °C; z is the z-value defined at 33°C and t is the time interval associated with each T (Mansfield, 1962).

2.3. Cook loss

Pre-cook weights of beef patties were determined prior to pan-fry cooking of the respective patties for the 3° of cook. After heat-treatment, meat patties were blotted onto paper napkins to remove surface oil and water, and the percentage of cook loss was determined using the formula: [(raw weight-cooked weight)/raw weight]×100 (Heath & Owens, 1990). Each analysis was performed in triplicate.

2.4. Color

Instrumental color evaluation of patties was determined using a Hunterlab "Labscan 6000' 0°/45°" Spectro Colorimeter (Hunter Associated Laboratories, Inc., Reston, VA). The meat color was read directly on the beef pattie surface contained in a plastic Petri plate (8.5 cm diameter and 1.4 cm depth). Hunter L^* (lightness), a^* (redness) and b^* (yellowness) values were obtained at three locations on each sample of ground beef. The mean values for L^*, a^* and b^* measurements were used to calculate chroma (color intensity) $= (a^2 + b^2)^{0.5}$, ΔE (color difference) $= [(\Delta L)^{2+}(\Delta a)^{2+}(\Delta b)^2]^{0.5}$ and a^*/b^* ratio.

2.5. Moisture

Moisture content of beef patties was determined on raw and cooked samples according to AOAC (1990) No. 950.46 method of analysis.

2.6. Shear force

Shear force measurements were conducted on beef patties using the TA-XT2 Texture Analyzer (Texture Technologies Corp., Scarsdal, New York), equipped with a single blade shear attachment (crosshead speed at 1.0 mm/s producing a contact force of 10.0 g). Three whole patties from each treatment were sheared at centre and individual values were expressed as gram force/gram sample.

2.7. Total crude lipid

Triplicate samples from raw, LHC and HHC cooked beef patties were weighed to 2.0 g and total lipids were extracted in chloroform/methanol (Folch, Lees, & Stanky, 1956). A modification to the procedure included rinsing the filtrate with chloroform:methanol (2:1) rather than with water.

2.8. Fatty acid profile analysis

Fatty acid methyl esters were derived from the total crude lipid according to the method of Morrison and Smith (1964). Modifications to the procedure included the addition of 0.5N KOH in methanol in a 50°C water bath for 60 min in the saponification step and the exclusion of an internal (C17:0) standard. After methylation, fatty acid methyl esters were quantified using a GC-17A flame ionization gas chromatograph (Mandel Scientific Co. Ltd., Guelph, ON), containing a fused silica capillary column (Omega wax 320^{TM}) with 0.32 mm internal diameter and 0.25 μm film thickness. The column was run isothermally at 200°C. The detector temperature was held at 260°C, and the injector temperature was maintained at 250°C.

2.9. Cholesterol analysis

Beef patty samples were analyzed for cholesterol according to the method of Park and Addis (1986), using a flame ionization gas chromatograph. Samples were prepared by extracting crude lipids from beef according to the method of Folch et al. (1957), followed by saponification and derivatization (Park & Addis, 1986). Derivatization was done at room temperature in KOH and diethyl ether to yield corresponding trimethylsilyl ether sterols. Samples were redissolved in pyridine and injected on a T-1 (15 m×0.25 mm I.D.×0.1) column (Sepelco). Quantitation was made from peak areas using 5 α-cholestane as the internal standard. All analyses were done in triplicate.

2.10. Statistical analysis

All data were analyzed by ANOVA using the General Linear Model Procedure of the Statistical Analysis

System (SAS, 1998) with a significance level of $\alpha \leqslant 0.05$. A multiple range test (Tukey test, SAS, 1998) was used to identify significant treatment means ($P \leqslant 0.05$).

3. Results and discussion

Heating of muscle tissue causes extensive changes in both physical and chemical properties, which are mostly dependent on the time–temperature conditions imposed during cooking. In the preliminary cooking trials, heating rate, cooking time and the temperature required to achieve a constant degree of cooked doneness were determined. Fig. 1 illustrates the heating curves for the HHT and LHT frying pans estimated with thermocouple. Heating rates at the centre of the HHT and LHT pans were determined to be 0.41 and 0.35°C/s, respectively. This result showed that the HHC pan had, on average, a higher rate of heat-transfer on the frying surface than the LHC surface.

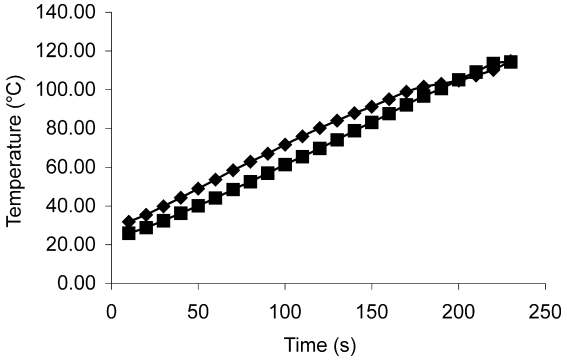

Fig 1. Heating curves for high heat transfer rate (HHT) and low heat transfer rate (LHT) frying surfaces with thermocouple placing at centre. ◆ HHT, ■LHT.

Fig. 2a–c illustrate the heating curves for the internal temperatures of ground beef patties cooked to first (1°), second (2°) and third (3°) degree of cook. In this trial, both frying pans were preheated to 100°C before cooking. Heating rates for patties, cooked using the HHT pan, were higher ($P \leqslant 0.05$) than those cooked using the LHT pan throughout the entire cooking process.

The L^* values were higher ($P \leqslant 0.05$) in the raw and LHT cooked patties than HHC cooked patties (Table 1), thus indicating that the surfaces of the patties were cooked to a greater extent on the HHC surface. Meat color is chiefly determined by the chemistry of myoglobin, type of ligand bound to heme, and state of the globin protein. Thus, upon heating, as in cooking, the globin protein will denature (Ledward, 1971), and the oxidation of purplish-red myoglobin (deoxymyoglobin), or of bright red oxymyoglobin to brown metmyoglobin is accelerated. On heating, red meat therefore turns to a brown color, due to the formation of ferric hemichromes. In the present study, however, changes in a^* (redness) values between patties employed at all levels of

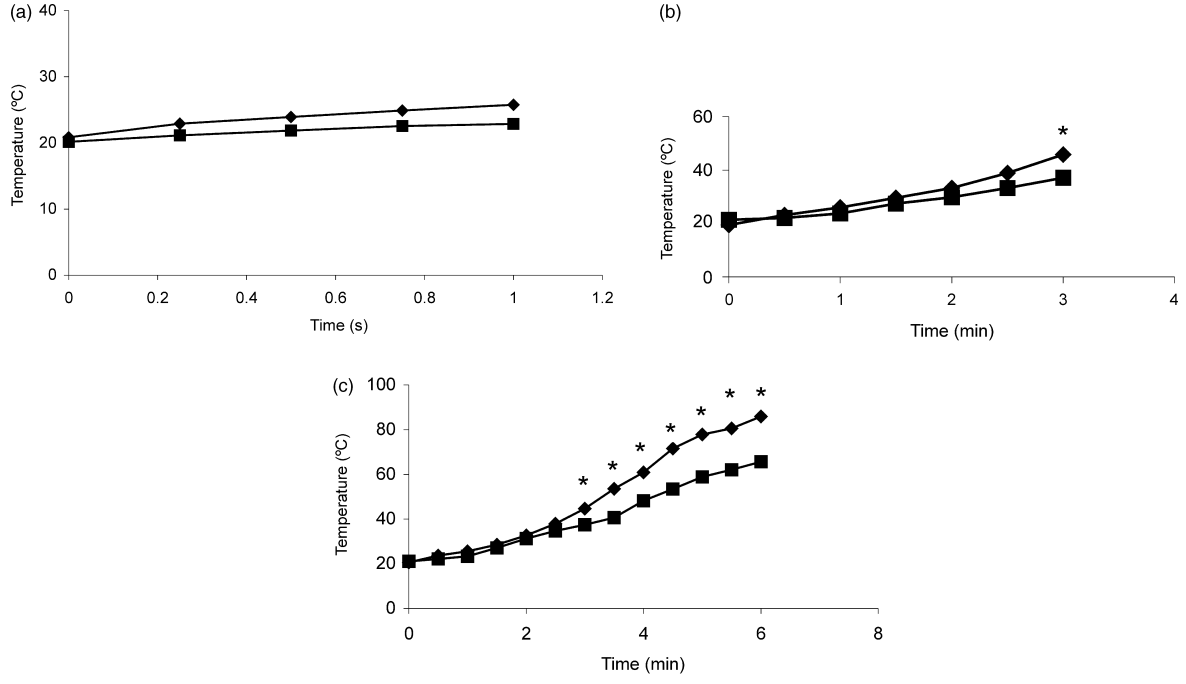

Fig. 2 (a). Heating curves for ground beef patties fried in high heat transfer rate (HHT) and low heat transfer rate (LHC) frying surface at 1° cook. Values represent means±S.E.M. ◆ HHT1°, ■ LHT1°. (b) Heating curves for ground beef patties fried in high heat transfer rate (HHT) and low heat transfer rate (LHT) frying surface at 2° cook. Values represent means±S.E.M. ◆ HHT2°, ■ LHT2°. Means were significantly different ($P \leqslant 00.5$). (c) Heating curves for ground beef patties fried in high heat transfer rate (HHT) and low heat transfer rate (LHT) frying surface at 3°cook. Values represent means±S.E.M. ◆ HHT3°, ■ LHT3°. Means were significantly different ($P \leqslant 00.5$).

Table 1
Values for HunterLab colour of beef patties cooked by two different cookwares and to 3° of cook[a]

Color parameters	Raw	Low heat-transfer rate			High heat-transfer rate		
		1°	2°	3°	1°	2°	3°
L^*	39.40a	31.10b	35.76c	31.28bd	25.97e	28.28f	29.40bf
(S.E.M.)	(0.17)	(0.46)	(0.08)	(0.25)	(0.46)	(0.46)	(0.52)
a^*	7.48a	7.25a	6.46a	5.22a	6.64a	6.36a	5.86a
(S.E.M.)	(0.24)	(0.35)	(0.17)	(0.07)	(0.11)	(0.03)	(0.07)
b^*	9.75a	8.01b	9.56ac	7.66b	7.79b	8.84cd	8.43d
(S.E.M.)	(0.22)	(0.18)	(0.08)	(0.05)	(0.20)	(0.33)	(0.13)
Chroma[b]	12.30a	10.81b	11.54abc	9.27cd	10.23b	10.89bc	10.26bcd
(S.E.M.)	(0.17)	(0.37)	(0.16)	(0.08)	(0.18)	(0.25)	(0.14)
ΔE[c]	0a	8.70 b	3.79c	8.70b	13.54d	11.22e	10.22be
(S.E.M.)	(0)	(0.31)	(0.13)	(0.21)	(0.43)	(0.48)	(0.53)
a^*/b^* ratio	0.77a	0.90b	0.68a	0.68a	0.85b	0.72a	0.70a
(S.E.M.)	(0.04)	(0.02)	(0.02)	(0)	(0.02)	(0.03)	(0.01)

[a] Means of three determinations; values in parentheses represent S.E.M. Means in the same row with different letters are different ($P \leqslant 0.05$)
[b] Chroma $= (a^2 + b^2)^{0.5}$.
[c] $\Delta E = [(\Delta L)^{2+} (\Delta a)^{2+} (\Delta b)^2]^{0.5}$.

Table 2
Values for heating-rate (°C/min), endpoint internal temperature (°C), cook loss (%) and shear force (g) of beef patties cooked by two different cookwares and to three degrees of cook[a]

	Raw	Low heat-transfer rate			High heat-transfer rate		
		1°	2°	3°	1°	2°	3°
Heating rate (°C/min)	–	2.73	5.13	5.96	4.00	7.23	10.77
Endpoint internal temperature (°C)	–	22.89	37.14	65.61	25.79	45.76	85.91
Cook value (min)	–	0.01	0.09	1.65	0.02	0.14	5.87
Cook loss (%)	0.00a	16.20b	24.52c	37.70d	23.57c	31.70e	46.89f
(S.E.M.)	(0.00)	(1.43)	(1.46)	(1.23)	(2.03)	(0.82)	(0.47)
Shear force							
(g/g sample;	32.34a	57.56b	66.66bc	105.06d	78.17ce	94.30de	107.43d
S.E.M.)	(3.33)	(2.38)	(5.43)	(8.42)	(6.74)	(2.14)	(7.01)

[a] Means of 3 determinations; values in parentheses represent S.E.M. Means in the same row with different letters are different ($P \leqslant 0.05$).

cook were not significant, indicating therefore, that the heat-transfer rate of frying surfaces was not a significant factor for the redness value. According to Roberts (1971), myoglobin is one of the more heat-stable of the sarcoplasmic proteins. Myoglobin denaturation occurs from enzymatic action or co-precipitation below 65°C, but is almost completely denatured within a temperature range of 80–85°C. Since the cooking temperatures used in our study were all below 65°C (except for HHC at 3° cook), the myoglobin was not totally denatured, thus having little effect on the a^* values. Other possible factors that may have contributed to the brown colour of cooked meat, include the caramelization of carbohydrates and Maillard reactions between reducing sugars and amino groups. Heat-transfer rates of frying surfaces only affected the b^* value at the 3° level. The LHT 3° was found to have a significantly lower ($P \leqslant 0.05$) b^* value than the HHT 3°. The ΔE values were higher ($P \leqslant 0.05$) in the HHC patties, indicating that using the HHT surface had the greatest effect on total color change in cooked samples.

Cook value is a measure of the cumulative heat impact of a complex time/temperature history on a food quality attribute. In the present study, cook value increased with the degree of cook (Table 2). A greater ($P \leqslant 0.05$) cook value was obtained in the HHT cooked patties when compared with samples cooked on the LHT surface at each level of cook ($P \leqslant 0.05$). The same trend was observed in cook loss. Cook loss in meat is derived from both aqueous and non-aqueous constituents. In this study, cook loss increased with the degree of cook (Table 2). For example, greater ($P \leqslant 0.05$) cook loss was observed in the HHT-cooked patties than with samples cooked on the LHT surface at each level of "doneness" ($P \leqslant 0.05$). Relatively high heating rates and endpoint internal temperatures, observed in the patties cooked on the HHT surface, corresponded to the greater endpoint temperatures, observed in these samples.

Shear force of cooked beef patties increased as the degree of cook increased (Table 2). A greater ($P \leqslant 0.05$) shear force was observed in the HHT-processed patties

than with the LHT patties. These results can be explained on the basis that meat toughness occurs partly due to water loss during cooking, thus resulting in an increase in shear force required to cut the muscle. This effect is due to the aggregation of the denatured myofibrillar proteins, primarly actomyosin, at low cooking temperature and shrinkage of the endomysium and perimysium collagens at high cooking temperature (Bailey & Light, 1989). Shrinkage of the perimysium and endomysium in beef patties forces out water which contributes to an increase in toughness.

The effect of cooking ground beef, using frying surfaces with characteristically different thermal heat transfer properties, on cholesterol content is shown in Fig. 3. Fresh, uncooked ground beef contained 36.8±4.02 mg cholesterol/100 g sample and had no detectable levels of cholesterol oxides. Cooking the ground beef to the primary degree of cook resulted in no loss of cholesterol in either LHT or HHT frying surfaces. It is important to note, however, that, although no significant loss of cholesterol occurred in beef cooked to a secondary degree of cook using the LHC surface, a dramatic loss ($P \leqslant 0.05$) of cholesterol was observed when the same beef sample was cooked to a secondary degree of cook on the HHT surface (e.g. 43.0±4.02% retention). Excessive cooking of ground beef to the third degree of cook resulted in significant ($P \leqslant 0.05$) losses of cholesterol on both the LHT (39.5±3.84%) and HHT (42.0±3.36%) frying surfaces. Cholesterol oxides were not detected in any of the cooked samples. The effect of cooking ground beef has previously been reported to result in significant (e.g. 46%) losses of cholesterol (Kritchevskey & Tepper, 1961), whereas other reports have indicated an increase in cholesterol due to cooking (Tu, Powrie, & Fennema, 1967). The similar high losses of cholesterol, especially in well-cooked ground beef patties, can be explained by the observations of others, that both drip-loss and cholesterol content in the drip are correlated with the fat level of the uncooked ground beef. For example, relatively greater losses of cholesterol were reported in the cook drip of beef patties containing 21% fat than in lean (e.g. 9.5% fat) patties (Kregel et al., 1986). The high losses of cholesterol in cooked, 19% fat beef patties, reported in our study, confirm the findings of other investigators who reported similar losses of sterol in relatively higher fat-containing beef samples (e.g. 21–28%). These findings, thus collectively challenge the notion that cooking of beef which contains more fat will result in the consumption of more cholesterol after cooking.

The fact that we did not observe significant differences in cholesterol in cooked beef patties processed to the first degree of cook in either the LHT or HHT surfaces, suggests that we did not reach a critical internal endpoint temperature required for significant losses of cholesterol to occur. Other workers, however, have reported that

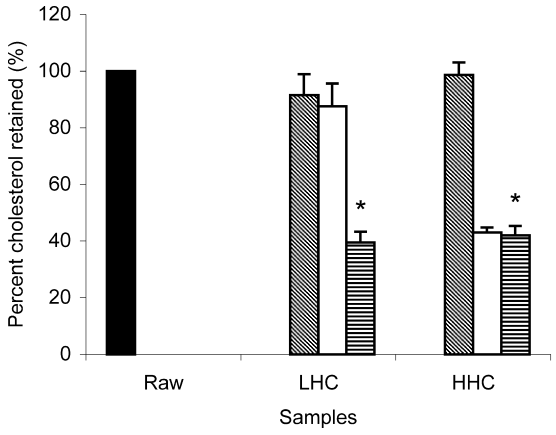

Fig. 3. Percent cholesterol retained in ground beef patties cooked in LHT and HHT surfaces and to three degrees of cook. Values represented means of three determinations ■ raw ▨ 1° □ 2° 3°. * Means were not significantly different ($P \leqslant 0.05$).

higher internal endpoint temperatures actually result in an apparent increase in cholesterol retention, which may be attributed simply to the greater evaporation of water and thus a higher proportion of cholesterol in the meat (Rhee et al., 1982). This explanation does not appear to explain our findings since, when comparing the percent loss of cholesterol with associated cook loss in samples processed on LHT and HHT frying surfaces, respectively, it is of interest to note that reaching a second degree of cook on the LHT frying surface was also insufficient to produce significant losses in sterol when compared with the HHT-cooked counterpart. The fact that significant cholesterol losses were observed only at high-cook value and when cook losses reached 30% or more, would indicate that a high final internal temperature is required to induce significant loss of cholesterol in heat processed meat. Although we could not detect the presence of specific cholesterol oxides in thermally-processed patties, probably because we did not analyze the composition of cook-loss liquids, it is known that losses of cholesterol in heated oil samples parallels the appearance of specific cholesterol oxide concentrations, relative to the temperatures used (Park & Addis, 1986). A similar suggestion for explaining losses of cholesterol in stored, cooked beef patties was made by Kregel et al. (1986). This possible explanation for the losses of cholesterol in patties processed on the HHT frying surface should not be ruled out, and warrants further investigation.

Changes in individual fatty acid composition of cooked beef patties were also observed in patties cooked on different heating surfaces (Table 3). Heat and moisture are both important factors influencing hydrolysis of ester bonds in lipids, resulting in the liberation of free fatty acids. In this study, an increase in the percentage of saturated fatty acids was observed in patties after cooking. In particular, C14:0 (myristic acid), C16:0 (palmitic acid) and C18:0 (stearic acid) were significantly

Table 3
Total crude lipid (%) and fatty acid profile (%) for beef patties cooked by two different cookwares and to three degrees of cook[a]

	Raw	Low heat-transfer rate			High heat-transfer rate		
		1°	2°	3°	1°	2°	3°
Total crude lipid (%)	19.46ab	17.43ab	18.55ab	17.77ab	17.86ab	16.64b	16.96ab
(S.E.M.)	(2.02)	(1.34)	(0.25)	(1.04)	(0.61)	(2.29)	(2.10)
Fatty acid							
C14:0	3.44a	3.39a	4.48ab	2.44ab	3.15ab	6.39b	6.10b
(S.E.M.)	(0.02)	(0.04)	(1.42)	(1.00)	(0.08)	(0.09)	(0.01)
C16:0	30.1a	29.8a	39.0a	46.4a	28.9a	57.3a	56.7a
(S.E.M.)	(0.10)	(0.27)	(12.36)	(22.94)	(0.41)	(0.43)	(0.10)
C16:1	0.54a	0.55a	0.72ab	0.41ab	0.55ab	1.05b	1.04b
(S.E.M.)	(0.00)	(0.02)	(0.24)	(0.17)	(0.00)	(0.02)	(0.02)
C18:0	16.9a	16.8a	22.2ab	12.7ab	17.2ab	32.6b	33.5b
(S.E.M.)	(0.22)	(0.10)	(7.30)	(5.39)	(0.24)	(0.64)	(0.23)
C18:1	48.4a	48.8a	32.9ab	37.6ab	49.5ab	1.32b	1.32b
(S.E.M.)	(0.30)	(0.38)	(21.2)	(16.1)	(0.47)	(0.10)	(0.05)
C18:2	0.23a	0.26a	0.39ab	0.20ab	0.31abc	0.51bcd	0.55bd
(S.E.M.)	(0.00)	(0.01)	(0.09)	(0.08)	(0.05)	(0.04)	(0.08)
C18:3	0.41a	0.43a	0.3a	0.33a	0.44a	0.85b	0.82b
(S.E.M.)	(0.01)	(0.00)	(0.17)	(0.14)	(0.02)	(0.02)	(0.02)
Total							
SFA[b]	50.5a	50.0a	65.7ab	61.5ab	49.2ab	96.3b	96.3b
MUFA[b]	48.9a	49.3a	47.0ab	38.0ab	50.1ab	2.37b	2.37b
PUFA[b]	0.64a	0.70a	0.69a	0.52a	0.75a	1.37b	1.37b

[a] Means of three determinations; values in parentheses represent S.E.M. Different letters indicate means for Raw, LHT and HHT differ ($P \leqslant 0.05$).

[b] SFA, saturated fatty acids (C14:0 + C16:0 + C18:0); MUFA, monounsaturated fatty acids (C16:1 + C18:1); PUFA, polyunsaturated fatty acids (C18:2 + C18:3).

($P \leqslant 0.05$) higher in samples cooked on the HHT frying surface, than in samples cooked on the LHT surface. There was also a significant ($P \leqslant 0.05$) decrease in MUFA after cooking, which may be due to the relatively low melting point of these fatty acids. Although controversy exists concerning the specific changes in individual fatty acids with most cooking methods (Cannell et al., 1989; Ono et al., 1985), our result, for the first time, shows how important cookware surface heat transfer properties are in changing the proportion of fatty acids in pan-fried beef patties. This was especially true for C18:1, which was lost to the greatest extent in the HHT cooked samples, compared with samples processed on the LHT cookware. Since there is evidence that, unlike saturated fatty acids, mono-unsaturated (n-9) fatty acids, may have specific health benefits, such as lowering serum cholesterol levels (Mattson & Grundy, 1985), we conclude that, in addition to considering the fatty acid components of beef pattie *per se*, other factors, such as the conditions of thermal processing of cooked beef, should be considered in estimating intake of specific dietary classes of fatty acids.

In conclusion, thermal heat conductivity rate of frying surfaces is an important factor on, not only the sensory perception of cooked ground beef, but also the lipid composition of processed patties. This study is only of academic interest in most circumstances. It is recommended to cook beef patties to an internal temperature of 70°C for 2 min before consumption, in order to ensure the microbial safety of the product.

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References

AOAC. (1990). *Official methods of analysis* (15th ed). Washington, DC: Assoc. of Official Analytical Chemists.

Bailey, A. J., & Light, N. D. (1989). *Connective tissue in meat products*. London: Elsevier Appl. Sci.

Cannell, L. E., Savell, J. W., Smith, S. B., Cross, H. R., & St. John, L. C. (1989). Fatty acid composition and caloric value of ground beef containingf low levels of fat. *Journal of Food Science*, *54*, 1163–1168.

Folch, J., Lees, M., & Stanley, G. H. (1956). A simple method for the isolation and purification of total lipids from animal tissues. *Journal of Biological Chemistry*, *226*, 497–501.

Heath, J. L., & Owens, S. L. (1990). Effects of high energy electron irradiation of chicken meat on Salmonella and aerobic plate count. *Poult. Sci.*, *69*, 150–156.

Janicki, L. J., & Appledorf, H. (1974). Effect of broiling, grill frying and microwave cooking on moisture, some lipid components and total fatty acids of ground beef. *Journal of Food Science*, *39*, 715–717.

Kregel, K., Prusa, K. G., & Hughes, K. U. (1986). Cholesterol content and sensory analysis of ground beef as influenced by fat level; heating and storage. *Journal of Food Science*, *51*, 1162–1165.

Kritchevsky, D., & Tepper, S. A. (1961). The fat and ester sterol content of rea foodstuffs. *Journal of Nutrition*, *74*, 441–447.

Ledward, D. A. (1971). On the nature of cooked meat haemoprotein. *Journal of Food Science*, *36*, 883–888.

Mansfield, T. (1962). High temperature-short time sterilization. *Proceedings of 1st International Congress on Food Science and Technology London, UK*, *4*, 311–316.

Mattson, F. H., & Grundy, S. M. (1985). Comparison of effects of dietary saturated, monounsaturated, and polyunsaturated fatty acids on plasma lipids and lipoproteins in man. *Journal of Lipid Research*, *26*, 194–202.

Morrison, W. R., & Smith, L. M. (1964). Preparation of fatty acid methyl esters and dimethylacetals from lipids with boron fluoride-methanol. *Journal of Lipid Research*, *5*, 600–607.

Ono, K., Berry, B. W., & Paroczay, E. (1985). Contents and retention of nutrients in extra lean, lean and regular ground beef. *Journal of Food Science*, *50*, 701–706.

Park, S. W., & Addis, P. B. (1986). Identification and quatitative estimation of oxidized cholesterol derivatives in heated tallow. *Journal of Agriculture and Food Chemistry*, *34*, 653–659.

Rhee, K. S., Dutson, T. R., & Smith, G. C. (1982). Effect of changes in intermolecular and subcutaneous fat levels on cholesterol content of raw and cooked steaks. *Journal of Food Science*, *47*, 1638–1645.

Roberts, T.A. (1971) Annual report. Meat research institute, Bristol. London: Churchill.

SAS (1998). *SAS User's Guide: Statistics*., Cary, NC: SAS Institute, Inc.

Statistics Canada. (1998). *http://www.statscan.ca*.

Tu, C., Powrie, W. D., & Fennema, O. (1967). Free and esterified cholesterol content of animal muscles and meat products. *Journal of Food Science*, *32*, 30–42.

Warris, P. D. (2000). *Meat Science*. New York: CABI Publishing.