陈学艳,王立振,廖中华,等. 胃排空检测方法的研究及展望[J].中国实验动物学报, 2019, 27(3):410 - 414.
Chen XY, Wang LZ, Liao ZH, et al. Methods and perspectives of application of gastric emptying detection techniques in laboratory animals [J]. Acta Lab Anim Sci Sin, 2019, 27(3):410 - 414.
Doi:10.3969/j.issn.1005-4847.2019.03.022

# 胃排空检测方法的研究及展望

陈学艳[1],王立振[3],廖中华[1],刘娟[1,2*]

(1. 西南大学动物科学学院中药创新实验室,重庆 荣昌 402460; 2. 重庆市高校兽医科学工程研究中心中兽药创新实验室,重庆 荣昌 402460)
3.江苏省原子医学研究所/卫生部核医学重点实验室/江苏省分子核医学重点实验室,江苏 无锡 214063)

**【摘要】** 胃排空是衡量消化道功能的一个重要指标,在探讨消化道疾病病因学、药物动力学以及疾病的诊断和治疗方面有着不可或缺的作用。近年来,一系列成熟的检测方法已经被用来测量人体胃排空,包括插管法、实时超声、放射性显像及呼吸试验等,但这些检测方法在实验动物及动物临床医学的应用还相对较少,正确评估实验动物胃排空能力的技术对于药物药理学、生物利用度和胃肠疾病诊断等的研究非常重要。本文就常用的几个胃排空检测方法做一阐述,希望这些方法能为动物胃排空检测提供新思路。

**【关键词】** 胃排空;插管法;实时超声;核素显像;呼吸试验
**【中图分类号】** Q95-33 **【文献标识码】** A **【文章编号】** 1005-4847(2019) 03-0410-05

# Methods and perspectives of application of gastric emptying detection techniques in laboratory animals

CHEN Xueyan[1], WANG Lizhen[3], LIAO Zhonghua[1], LIU Juan[1,2*]

(1. Department of Veterinary Medicine, Southwest University, Rongchang, Chongqing 402460, China. 2. Veterinary Science Engineering Center of Traditional Chinese Medicine Innovation Research Laboratory Chongqing, Chongqing 402460. 3. Key Laboratory of Nuclear Medicine, Ministry of Health, Jiangsu Key Laboratory of Molecular Nuclear Medicine, Jiangsu Institute of Nuclear Medicine, Wuxi 214063)
Corresponding author: LIU Juan. E-mail: liujrc@163.com

**【Abstract】** Gastric emptying is important for measuring digestive tract function and plays an indispensable role in the research on etiology, diagnosis and treatment of digestive diseases. In recent years, a series of detection methods has been used to measure gastric emptying in humans: intubation, real-time ultrasound, radionuclide imaging and respiratory testing. However, these method are relatively rarely used in laboratory animals. A method for evaluating the gastric-emptying ability of laboratory animals correctly is very valuable for the study of the drug bioavailability and gastrointestinal diseases. In this review, we discuss some of the methods commonly used for detection of gastric emptying in humans. We hope that we can provide some new ideas for detection of gastric emptying in animals.

**【Keywords】** gastric emptying; intubation; real-time ultrasound; radionuclide imaging; respiratory testing
Conflicts of Interest: The authors declare no conflict of interest.

[**基金项目**]国家公益性行业(农业)科研专项(201303040-05);农业部科技基础性工作专项(2013FY110600-03)。
Funded by National Public Welfare Industry (Agriculture) Special Scientific Research (201303040-05), and Special Science and Technology Foundation Work of Ministry of Agriculture (2013FY110600-03).
[**作者简介**]陈学艳(1995—),女,在读硕士研究生,从事中兽药研究。Email:1054396452@qq.com
[**通信作者**]刘娟,女,博士,硕士生导师,主要从事中兽药研究。Email:liujrc@163.com

胃排空(gastric emptying, GE)是指食物由胃排入十二指肠的过程,由多种因素共同调节而完成,主要依赖于近端和远端胃收缩活动的协调以及幽门和小肠通过内外神经系统和神经体液途径之间复杂的相互作用[1]。这一过程中的因素包括乙酰胆碱和神经肽 P 物质以及抑制性介质,如 VIP 肽(也称为血管活性肠肽)、一氧化碳和一氧化氮等,它们能促进肌肉收缩[2],受中枢神经系统、迷走神经、循环肽类激素等的调节,因此,动物的情绪[3]、机体内激素[4]、血糖[5]、食物的理化特征[6]等均能引起胃排空的异常。研究表明,食物的粘度对胃排空率会造成一定的影响,增加半固体营养性膳食的粘度能调节血糖并影响餐后饱腹感,从而影响机体胃排空率[6-7]。但是对于非营养性膳食,食物粘度对胃排空率的影响相对较小[8]。

由于胃排空参与了许多疾病的病理生理过程,因此胃排空异常可提示胃肠蠕动功能异常、血糖代谢疾病等多种疾病的发生,如一些慢性疾病、帕金森病、功能性消化不良、胃食管反流、代谢综合征、营养不良等均可引起胃排空异常[9-11]。研究报道,胃排空延迟可能与机体血糖控制有关,高血糖可使胃排空延迟,反之,低血糖可使胃排空加速。Hebbard 等[12]发现,在禁食状态下,诱导高血糖可降低胃窦活动性,增强孤立幽门压力波群(IPPWS),改变十二指肠动力,降低近端胃动力,导致胃排空的延迟。近年来的研究报道也说明胃排空和血糖之间存在着一种复杂的双向关系——胃排空占健康个体和糖尿病患者的餐后血糖浓度差异的 35%,而胃排空率本身是受血糖的急性变化调节[13]。因此在糖尿病患者中,经常出现胃排空紊乱现象[14, 15]。同样,帕金森疾病(Parkinson's disease, PD)也可导致胃动力不足而使胃排空延迟,Goetze 等[16]研究发现,未经治疗的 PD 患者中,约 16%的患者有恶心症状,43%有腹胀感,近 100%的 PD 患者均存在胃动力障碍[17],继而引发恶心、腹胀。最近有研究表明几乎所有的 PD 患者都会出现胃肠功能紊乱,影响药物药效,导致生活质量受损;并有可能加强患者的胃肠运动波,导致机体功能恶化,从而进一步残疾[18]。因此,通过有效方法测定胃排空,对于临床上胃肠生理功能的评价以及消化道功能异常的诊断很有必要。

在以往的动物实验中,大多采用直接解剖动物观察胃内食物残留量来判断体内胃排空的情况,这种方法有悖于动物福利规定,且该方法仅能确定胃排空的状态,对于动物的消化道状况并不能给出一个完整的评价。目前,临床上检测胃排空的方法主要有插管法、实时超声法、$^{13}C$ 辛酸盐呼气试验、放射性核素显像法等。尽管早些年实时超声[19]、呼吸试验[20]及放射性核素显像[21]等方法作为一种无创性评价胃排空的方法,且有研究已应用于评价犬、猫等动物胃肠情况,但各方法均具有一定的局限性[22]。本文就几种临床常见胃排空测定方法做一简述,并对其动物临床中的应用前景进行展望。

## 1　插管法

临床上最早用于测定胃排空的插管法是 Hunt 等[23]创立的双样本浓度差法,该方法可以准确测定胃排空的情况。具体方法是进试验餐后,置胃管,先抽取胃液为样本 1,再注入两倍于样本体积的浓缩标志物,混匀后,再取与样本 1 等体积胃液为样本 2。根据两次样本浓度,推算当时胃内残余液体量。在不同时间间隔下重复上述检查,即可得到胃排空的动态变化。后来 George[24]发明了双重抽样法,在抽样的同时加入酚红染料,该方法能在观察胃排空情况的同时计算出胃内容物的体积,并能够观察胃液分泌对胃体积的影响[25]。由于插管法检查方法相当繁琐,需要反复插管,侵入性较强,且插管法更多适用于检测液体胃排空[26]。随着核素显像及其他非侵入性方法的应用,目前该法已很少用于检测人体胃排空,在动物身上也鲜有报道。尽管插管法侵入性较强,但它相对于其他测定方法可以更为精确的提供胃排空过程的信息,因此该方法常用于验证其他方法的准确性[27]。

## 2　实时超声法

超声检查是一种无创性的研究方法,它能深入了解人体胃排空、功能性疾病和胃肠道动力障碍情况,实时超声技术由于其无创性和相对较低的成本,是研究胃动力的一种潜在的有价值的工具[28]。超声检查迄今主要包括三种检测方法:全胃体积法、胃窦体积法、胃窦单切面积法,目前多采用胃窦单切面积法。1980 年,Holt 等[29]首次用超声研究液体试验餐后全胃收缩情况。1982 年,Bateman 等[30]首先应用实时超声测定液体胃排空,进餐后,通过动态监测从胃底到胃窦一系列不同切面径线的变化,计算胃腔容积,获得不同时间点胃容积的

变化,以了解胃排空情况。1985 年,Bolondi 等[31]简化该方法,利用胃窦横截面积在不同的时间段测定胃排空值,确定混合餐总胃排空时间。然而,腹部超声在测定固体胃排空方面存在局限性,由于进食固体食物后胃壁回声较高,很难鉴别[32]。它还需要结合临床或内镜检查来诊断病变,同时,检查人员也需要有熟练的超声检查技术,且对于肥胖患者,超声检测难度更大[33]。不过由于超声检查具有廉价、无放射性等优点,已经成为近年来研究的一个热点[32]。Hamada 等[34]用超声检测危重病人胃窦横截面积并计算其胃容积大小,说明实时超声法在危重病患特别是具有吸入困难的病患身上,测定其胃排空具有可行性和有效性。临床上已经有实时超声对孕妇及新生儿进行胃排空的检测,侧面反应了超声的安全性等特点[35-36]。相比于其他方法,超声的无放射性和无创性,更有利于在孕畜及新生幼畜的胃排空检测。

## 3 放射性核素显像法

放射性核素显像法一直以来被认为是测定胃排空功能的“金标准”,能在机体正常生理状态下对胃排空功能进行检测,对消化道疾病病因学探讨和胃肠道功能研究具有重要的临床价值[37]。放射性核素显像技术是利用放射性标记的底物在脏器和病变组织中的摄取、滞留等的差异,通过显像仪器显影脏器或病变组织进行诊断的方法。放射性元素及示踪剂的选择至关重要,临床常用的胃排空示踪剂有$^{99m}$Tc-DTPA[38]、$^{99m}$Tc-硫胶体[38]、$^{99m}$Tc-白蛋白胶体[39]等,选择锝元素($^{99m}$Tc)的主要原因是$^{99m}$Tc半衰期较短(约 6 h),与 DTPA 等螯合物结合后口服不容易被食管和胃黏膜吸收[40]。目前该方法的优异作用已在大鼠及小鼠实验中得到验证[41-42],其具体操作为大鼠在禁食 12 h 后接受所提供的含有放射性标记物的试餐,将大鼠仰卧固定,利用 SPECT 探头进行图像采集。随着时间推移,胃内放射性逐渐降低,在半对数坐标图上,绘出不同时间全胃的轮廓,计算出全胃内的放射性计数,使用编制的软件计算胃内食物排除 50%所需的时间即胃半排空时间($GET_{1/2}$),以此作为胃排空的指标[41]。放射性核素显像在临床胃排空检测中同样显示出了良好的效果,Amiriani 等[43]利用 SPECT 对 24 例功能性消化不良患者进行胃排空显像,结果显示功能性消化不良患者空腹胃容积、餐后胃容积均明显低于对照组($P< 0.05$)。因此 SPECT 可作为测量胃容积及诊断功能性消化不良的一种有价值的方法。放射性核素显像具有操作简便、无侵入性、符合生理条件、灵敏准确等优点,对判断病情与观察疗效有一定临床价值,但该方法因具有放射性且检查价格昂贵,目前临床应用被限制。

## 4 $^{13}$C 辛酸盐呼气试验

$^{13}$C 辛酸盐呼气试验因其具有非侵入性、安全、可重复等优点,与核素显像法比较具有较好的一致性和相关性,目前已在临床上普及[20, 44]。呼气试验的原理是将同位素$^{13}$C 与游离脂肪酸(如辛酸/乙酸)结合后作为标志物与食物混合制成试验餐,受试者在口服试餐后,$^{13}$C 辛酸经胃排空迅速在十二指肠被吸收并在肝中代谢,氧化后形成 $CO_2$经呼气排出[45-46]。再应用同位素比值质谱仪等设备检测,经过特定公式计算即可得到胃排空参数[47]。近年来已有学者将$^{13}$C 辛酸盐呼气试验应用到马、猪、狗、猫等动物胃排空的测定[48-49]。Sutton 等[49]在探讨阿托品致使马胃排空延迟试验中,利用$^{13}$C 辛酸盐呼气法测得马属动物正常生理盐水排空时间及胃排空延迟时间分别为(6.76 ± 1.65)和(2.52 ± 0.35)h,两组间的差异呈正态分布,且有显著性($P< 0.001$)。结果证明,$^{13}$C 辛酸盐呼气试验对检测阿托品引起的动物胃排空延迟有足够的敏感性。同样,Jørgensen 等[49]发现$^{13}$C 辛酸盐呼气试验对估计妊娠母猪的胃排空情况具有可行性。因此,$^{13}$C 辛酸盐呼气试验也适用于评估动物胃排空。

## 5 小结及展望

胃排空速度是衡量动物消化道运动机能的主要指标之一。上述的超声、核素显像在人体临床较为常用,但在动物临床上并不普及。经典的动物实验方法是手术安装各种瘘管,待伤口愈合、恢复正常后开始做实验。此方法由于手术操作复杂,且若术后护理不当易发生感染。因此,开发新型无创、简捷、精确定量的胃排空测定方法具有重要意义。

放射性核素显像法作为测定胃排空的“金标准”,能够测定动物在正常生理状态下不同状态下食物的胃排空情况,具有操作简便、无侵入性、符合生理条件、灵敏准确等特点,能够通过显像直观的观察生理状态下胃动力及消化道情况,第一时间诊断病情,对疾病诊断具有一定的价值[50]。但目前的

SPECT(单光子发射计算机断层成像术)显像灵敏度和分辨率都较低,只能相对定量[51]。近年来,正电子发射计算机断层扫描(PET)的出现促进了分子影像的发展。PET 是唯一能在体内显示生物分子代谢、受体和神经元活性的新成像技术,此外,它还可用于预后疾病复发[52]。PET 具有灵敏度高、特异性高、定量准确等优点,其灵敏度是 SPECT 的 10 倍以上,可检出 1.4 mm 大小的病灶,图像清晰,诊断准确率高[53]。尽管 PET 胃排空显像存在价格昂贵等问题,但因其具有活体检测及精确测量等功能特色,且操作简单、快捷,更具推广应用前景。

## 参 考 文 献(References)


[1] Stevens JE, Jones KL, Rayner CK, et al. Pathophysiology and pharmacotherapy of gastroparesis: current and future perspectives [J]. Expert Opin Pharmacother, 2013, 14(9): 1171-1186.

[2] Gillis M, Koch KL. Gastroparesis: Pathophysiology of Chronic Abdominal Pain and Current Treatment [M]. Springer, New York, 2015.

[3] Dibaise JK, Islam RS, Dueck AC, et al. Psychological distress in Rome III functional dyspepsia patients presenting for testing of gastric emptying [J]. Neurogastroenterol Moti, 2016, 28(2): 196-205.

[4] Sun L, Tan K, Han C, et al. Impact of preloading either dairy or soy milk on postprandial glycemia, insulinemia and gastric emptying in healthy adults [J]. Eur J Nutr, 2017, 56(1): 77-87.

[5] Mcwhorter NE, Abazid L, Gorzell BC, et al. Simultaneous blood glucose monitoring during gastric-emptying scintigraphy may identify unsuspected abnormalities [J]. Clin Nucl Med, 2018, 43(6): 411.

[6] Yong Z, Hsu WH, Hollis JH. The impact of food viscosity on eating rate, subjective appetite, glycemic response and gastric emptying rate [J]. PLoS One, 2013, 8(6): e67482.

[7] Moxon TE, Nimmegeers P, Telen D, et al. Effect of chyme viscosity and nutrient feedback mechanism on gastric emptying [J]. Chem Eng Sci, 2017, 171: 318-30.

[8] Shimoyama Y, Kusano M, Kawamura O, et al. High-viscosity liquid meal accelerates gastric emptying [J]. Neurogastroenterol Motil, 2010, 19(11): 879-886.

[9] Wang KY, Chen YW, Wang N, et al. Predictor of slower gastric emptying in gastroesophageal reflux disease-survey of an Asian-Pacific cohort [J]. J Gastroen Hepatology, 2018.

[10] Knudsen K, Szwebs M, Hansen A K, et al. Gastric emptying in Parkinson's disease - a mini-review [J]. Parkinsonism Relat Disord, 2018, 55: 18-25

[11] Caldaro T, Angelis PD, Torroni F, et al. Gastroenterology: Gastric Emptying - Gastroesophageal Reflux [M]. Springer International Publishing, 2017.

[12] Hebbard GS, Sun WM, Dent J, et al. Hyperglycaemia affects proximal gastric motor and sensory function in normal subjects [J]. Eur J Gastroenterol Hepatol, 1996, 8(3): 211-217.

[13] Marathe CS, Rayner CK, Jones KL, et al. Relationships between gastric emptying, postprandial glycemia, and incretin hormones [J]. Diabetes Care, 2013, 36(5): 1396-1405.

[14] Alipour Z, Khatib F, Tabib S M, et al. Assessment of the prevalence of diabetic gastroparesis and validation of gastric emptying scintigraphy for diagnosis [J]. Mol Imaging Radionucl Ther, 2017, 26(1): 17-23.

[15] Borg MJ, Bound M, Grivell J, et al. Comparative effects of proximal and distal small intestinal administration of metformin on plasma glucose and glucagon-like peptide-1, and gastric emptying after oral glucose, in type 2 diabetes [J]. Diabetes Obes Metab, 2018, 21(3): 640-647.

[16] Goetze O, Nikodem AB, Wiezcorek J, et al. Predictors of gastric emptying in Parkinson's disease [J]. Neurogastroenterol Motil, 2010, 18(5): 369-375.

[17] Lee HJ, Jung KW, Sun JC, et al. Relation of enteric α-synuclein to gastrointestinal dysfunction in patients with parkinson's disease and in neurologically intact subjects [J]. J Neurogastroenterol Motil, 2018, 24(3): 469-478.

[18] Ramprasad C, Douglas JY, Moshiree B. Parkinson's disease and current treatments for its gastrointestinal neurogastromotility effects[J]. Curr Treat Options Gastroenterol, 2018, 16(4): 489-510

[19] Song IK, Kim HJ, Lee JH, et al. Ultrasound assessment of gastric volume in children after drinking carbohydrate-containing fluids [J]. Br J Anaesth, 2016, 116(4): 513-517.

[20] Muangchan N, Kooptiwut S, Tapechum S, et al. $^{13}$C-acetic acid breath test monitoring of gastric emptying during disease progression in diabetic rats [J]. Biol Pharm Bull, 2017, 40(9): 1506-1514.

[21] Henrichon S, Seltzer M, Siegel A. Use of SPECT/CT to confirm inconclusive gastric emptying scintigraphy results [J]. Clinl Nucl Med, 2015, 40(6): 341-342.

[22] Christopher RL. Recent developments in diagnostic imaging of the gastrointestinal tract of the dog and cat [J]. Vet Clini North Am Small Anim Pract, 1999, 29(2): 341-342.

[23] Hunt JN, Spurrell WR. The pattern of emptying of the human stomach [J]. J Physiol, 1951, 113(2-3): 157-168.

[24] George JD. New clinical method for measuring the rate of gastric emptying: the double sampling test meal [J]. Gut, 1968, 9(2): 237-242.

[25] Leiper JB, Nicholas CW, Ajmol A, et al. The effect of intermittent high-intensity running on gastric emptying of fluids in man [J]. Med Sci Sports Exerc, 2005, 37(2): 240-247.

[26] Blake G, Mckelvey ST. The measurement of gastric emptying: a comparison of fixed scintillation detection and the double-sampling technique [J]. Br J Surg, 2010, 68(6): 393-396.

[27] Shi X, Osterberg KL, Petrie H, et al. Effect of different osmolalities, cho types, and [cho] on gastric emptying in humans [J]. Med Sci Sports Exerc, 2016, 49(5): 1015-1021.

[28] Muresan C, Surdea BT, Muresan L, et al. Abdominal ultrasound for the evaluation of gastric emptying revisited [J]. J Gastrointestin Liver Dis, 2015, 24(3): 329-338.

[29] Holt S, Mcdicken WN, Anderson T, et al. Dynamic imaging of the stomach by real-time ultrasound — a method for the study of gastric motility [J]. Gut, 1980, 21(7): 597-601.

[30] Bateman DN, Whittingham TA. Measurement of gastric emptying by real-time ultrasound [J]. Gut, 1982, 23(6): 524-527.

[31] Bolondi L, Bortolotti M, Santi V, et al. Measurement of gastric emptying time by real-time ultrasonography [J]. Gastroenterology, 1985, 89(4): 752-759.

[32] Liu Z, Liu Z, Li Y, et al. Evaluation of gastric emptying by transabdominal ultrasound after oral administration of semisolid cellulose-based gastric ultrasound contrast agents [J]. Ultrasound Med Biol, 2018, 44(11): 2183-2188.

[33] Schepper HUD, Cremonini F, Chitkara D, et al. Assessment of gastric accommodation: overview and evaluation of current methods [J]. Neurogastroenterol Motil, 2010, 16(3): 275-285.

[34] Hamada SR, Garcon P, Ronot M, et al. Ultrasound assessment of gastric volume in critically ill patients [J]. Intensive Care Med, 2014, 40(7): 965-972.

[35] Christopher W, Jose J, Alan D, et al. In vivo ultrasound assessment of gastric emptying in newborn mice [J]. J Pediatr Gastroenterol Nutr, 2015, 60(3): 322-326.

[36] Sümpelmann AE, Sümpelmann R, Lorenz M, et al. Ultrasound assessment of gastric emptying after breakfast in healthy preschool children [J]. Paediatr Anaesth, 2017, 27(8).

[37] Hafeez M, Hussain F, Salamat A, et al. Gastric emptying scintigraphy in postprandial distress syndrome [J]. Pak J Medl Sci, 2018, 34(1): 27-31.

[38] Marathe PH, Wen Y, Norton J, et al. Effect of altered gastric emptying and gastrointestinal motility on metformin absorption [J]. Br J Clin Pharmacol, 2015, 50(4): 325-332.

[39] Lam MG, Goris ML, Iagaru AH, et al. Prognostic utility of 90Y radioembolization dosimetry based on fusion 99mTc-macroaggregated albumin-99mTc-sulfur colloid SPECT [J]. J Nucl Med, 2013, 54(12): 2055-2061.

[40] Phillips LK, Rayner CK, Jones KL, et al. Measurement of gastric emptying in diabetes [J]. J Diab Compl, 2014, 28(6): 894-903.

[41] Bennink RJ, Jonge WJ, De, Symonds EL, et al. Validation of gastric-emptying scintigraphy of solids and liquids in mice using dedicated animal pinhole scintigraphy [J]. J Nuclear Med, 2003, 44(7): 1099-1104.

[42] Jang SF, Goins BA, Phillips WT, et al. Size discrimination in rat and mouse gastric emptying [J]. Biopharm Drug Dispos, 2013, 34(2): 107-124.

[43] Amiriani T, Javadi H, Raiatnavaz T, et al. Assessment of gastric accommodation in patients with functional dyspepsia by 99mtc-pertechtenate single photon emission computed tomography imaging: practical but not widely accepted [J]. Mol Imaging Radionucl Ther, 2015, 24(3): 105-109.

[44] Suzuki J, Shimazaki K, Koike S, et al. Gastric emptying rate before and after orthodontic treatment examined with the [$^{13}$C] breath test: A pilot study [J]. Am J Orthod Dentofacial Orthop, 2018, 153(3): 347-354.

[45] Symonds E, Butler R, Omari T. Noninvasive breath tests can detect alterations in gastric emptying in the mouse [J]. Eur J Clin Invest, 2015, 32(5): 341-344.

[46] Sanaka M, Yamamoto T, Y. Retention, fixation, and loss of the (13C) label: a review for the understanding of gastric emptying breath tests [J]. Dig Dis Sci, 2008, 53(7): 1747-1756.

[47] Shin AS, Camilleri M. Diagnostic assessment of diabetic gastroparesis [J]. Diabetes, 2013, 62(8): 2667-2673.

[48] Sutton DG, Bahr A, Preston T, et al. Quantitative detection of atropine-delayed gastric emptying in the horse by the$^{13}$C-octanoic acid breath test [J]. Equine Vet J, 2010, 34(5): 479-485.

[49] Jørgensen H, Strathe A, Theil PK, et al. Evaluation of a simple non-invasive$^{13}$C breath test to evaluate diet effects on gastric emptying in pigs [J]. Livest Sci, 2010, 133(1): 64-66.

[50] Camilleri M, Parkman H P, Shafi M A, et al. Clinical guideline: management of gastroparesis [J]. Am J Gastroenterol, 2013, 108(1): 18-37.

[51] Kjaer A, Knigge U. Use of radioactive substances in diagnosis and treatment of neuroendocrine tumors [J]. Scand J Gastroenterol, 2015, 50(6): 740-747.

[52] Hou C, Hsieh CJ, Li S, et al. Development of a positron emission tomography radiotracer for imaging elevated levels of superoxide in neuroinflammation [J]. ACS Chem Neurosci, 2018, 9(3): 578-586.

[53] Pantel AR, Mankoff DA. Molecular imaging to guide systemic cancer therapy: illustrative examples of PET imaging cancer biomarkers [J]. Cancer Lett, 2017, 387:25-31

[收稿日期] 2018-11-16