

# Assessment of five portable blood glucose meters, a point-of-care analyzer, and color test strips for measuring blood glucose concentration in dogs

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**Objective**—To compare blood glucose concentrations obtained using a point-of-care (POC) analyzer, 5 portable blood glucose meters (PBGM), and a color reagent test strip with concentrations obtained using a reference method, and to compare glucose concentrations obtained using fresh blood samples in the PBGM with concentrations obtained using blood anticoagulated with lithium heparin.

**Design**—Case series.

**Sample Population**—110 blood samples from 34 dogs; glucose concentration of the samples ranged from 41 to 596 mg/dl.

**Procedure**—Logistic regression was used to compare blood glucose concentrations obtained with the various devices with reference method concentrations. Ease of use was evaluated subjectively. Percentage of times a clinical decision would have been altered if results of each of these methods had been used, rather than results of the reference method, was calculated.

**Results**—For 3 of the PBGM, blood glucose concentrations obtained with fresh blood were not significantly different from concentrations obtained with blood samples anticoagulated with lithium heparin. None of the devices provided results statistically equivalent to results of the reference method, but the POC analyzer was more accurate than the others. For some samples, reliance on results of the PBGM or the color test strip would have resulted in erroneous clinical decisions.

**Conclusions and Clinical Relevance**—Although commercially available PBGM and color test strips provided blood glucose concentrations reasonably close to those obtained with reference methods, some devices were more accurate than others. Use of results from these devices could lead to erroneous clinical decisions in some cases. (*J Am Vet Med Assoc* 2000;216:198–202)

**K**nowledge of an animal's blood glucose concentration is critical to many diagnostic and therapeutic decisions in veterinary medicine, particularly when

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treating animals with diabetes mellitus or conditions that may cause hypoglycemia. Various methods for measuring blood glucose concentration have been developed. Most commercial diagnostic laboratories use automated chemistry analyzers that determine glucose concentration by means of a hexokinase or glucose oxidase method. Other widely used methods for determining blood glucose concentration involve enzyme-catalyzed reactions coupled to a color detection system, oxidation-reduction methods, and methods that result in generation of an electrical current.<sup>1</sup>

People with diabetes mellitus are often taught to monitor their own blood glucose concentrations as a means of maintaining glycemic control.<sup>2</sup> A number of **portable blood glucose meters (PBGM)** have been developed that permit people to use a drop of capillary blood to determine blood glucose concentration. These meters use a number of glucose detection technologies, but most employ a method based on the enzymatic reaction between glucose in the blood sample and glucose oxidase. Because these meters are readily available and inexpensive and can rapidly provide results from small quantities of blood, many veterinarians have used them to measure blood glucose concentration in dogs. However, when measuring blood glucose concentration in dogs, many veterinarians use venous blood, instead of the capillary blood most of the available meters were designed to use.

As use of these PBGM has become more popular, so too has use of **point-of-care (POC)** analyzers. Point-of-care analyzers typically use various cartridges to measure a number of biochemical parameters in addition to blood glucose concentration. Like PBGM, POC analyzers require only small amounts of whole blood and provide results rapidly. However, POC analyzers are more expensive than PBGM and are designed to be used by health care professionals.

The purpose of the study reported here was to compare, for blood samples from dogs, glucose concentrations obtained using a POC analyzer, 5 commercially available PBGM, and a color test strip with concentrations obtained using an automated analyzer that determined concentration by use of a glucose oxidase reference method. In addition, we wanted to compare concentrations obtained using fresh blood samples in the PBGM with concentrations obtained using blood anticoagulated with lithium heparin.

## Materials and Methods

**Dogs**—Thirty-four dogs and a total of 110 blood samples were used in the study. Five dogs (21 blood samples)

were healthy, 14 dogs (46 blood samples) had diabetes mellitus, and the remaining 13 dogs (43 blood samples) had a variety of medical conditions, including insulinoma (2 dogs). All owners permitted collection of blood samples from their pets. Glucose concentration of the blood samples, determined by use of the reference method, ranged from 41 to 596 mg/dl (mean, 211 mg/dl; median, 141 mg/dl; mode, 98 mg/dl).

**Experimental protocol**—Blood samples were collected from the jugular or cephalic vein, using a 20- or 22-gauge needle, and placed in tubes containing lithium heparin.<sup>a</sup> To determine whether use of fresh or anticoagulated blood had an effect on results obtained with the 5 PBGM, dogs were manually restrained while a needle was placed in the cephalic vein. Blood was allowed to drip directly from the needle hub onto the PBGM test strip or cartridge and was assayed immediately. After all strips and cartridges were wetted, a 1 ml syringe was attached to the needle, and 400  $\mu$ l of blood was collected and placed in a tube containing lithium heparin.<sup>a</sup>

Anticoagulated blood samples were assayed within 10 minutes after collection. All PBGM were operated according to the manufacturers' directions, with the exception that venous, rather than capillary, blood was used. Meters were calibrated as directed by the manufacturers. For the POC analyzer, cartridges designed to measure only blood glucose concentration were used; the analyzer was operated according to manufacturer's directions. All assays involving the PBGM, the POC analyzer, and the color test strip were performed by the investigators. Immediately after aliquots needed for use with the PBGM, the POC analyzer, and the test strip were removed, the remainder of each anticoagulated blood sample was centrifuged, and plasma was obtained. Plasma glucose concentrations were measured by use of a standard dry chemistry automated analyzer<sup>b</sup> by trained laboratory personnel who were unaware of the results obtained from other devices.

**Description of analyzers**—The automated analyzer used to obtain reference blood glucose concentrations employs a multilayered dry slide technique. Glucose in the sample diffuses through a porous top film onto a film impregnated with glucose oxidase and other reagent chemicals. The end product of the chemical reaction is a colored dye; the intensity of the color change is measured through a lower transparent film by means of reflectance spectrophotometry. Precision and accuracy data provided by manufacturers of devices using identical methodology reveal coefficient of variations < 1.7%, with correlation coefficients of 0.99 to 1.0. The analyzer was calibrated daily, using commercial quality control standards with high glucose concentrations and concentrations within the reference range.

Five PBGM were used in the study. Three of these meters measured glucose concentration by means of enzymatic reactions coupled to chromogen alterations that were then detected via reflectance photometry. The other 2 measured concentration by means of electrochemical reactions in which the electrical current was proportional to the glucose concentration. The POC analyzer used in the study measured glucose concentration by means of an electrochemical reaction.

Five PBGM were used in the study: the **Glucometer Glucofilm** (Glucofilm),<sup>c</sup> the **Glucometer Encore** (Encore),<sup>d</sup> the **Accu-Chek Easy** (Accu-Chek),<sup>e</sup> the **ExacTech RSG** (ExacTech),<sup>f</sup> and the **Glucometer Elite** (Elite).<sup>g</sup>

The Glucofilm meter measured glucose concentration by means of a glucose oxidase reaction; results were detected by means of reflectance photometry. Blood had to be manually wiped from the strip prior to insertion in the meter for

reading. Detectable glucose concentrations ranged from 20 to 500 mg/dl. The manufacturer stated that venous blood could be used.

The Encore meter used reflectance photometry to measure production of a colored chromogen resulting from a reaction catalyzed by glucose dehydrogenase. Manual wiping of blood from the test strip was not necessary. Detectable glucose concentrations ranged from 10 to 600 mg/dl.

The Accu-Chek meter used reflectance photometry to measure production of a colored chromogen by a glucose oxidase-peroxidase reaction. Manual wiping of blood from the test strip was not necessary. Detectable glucose concentrations ranged from 20 to 500 mg/dl. The manufacturer specifically stated that venous blood should not be used.

The ExacTech meter measured glucose concentration by measuring electrical currents after the blood sample underwent a chemical reaction with the test strip. Detectable glucose concentrations ranged from 40 to 450 mg/dl. The manufacturer stated that venous blood could be used if the assay was performed within 15 minutes of blood collection.

The Elite meter measured glucose concentration by measuring electrical currents after the blood sample underwent a chemical reaction with the test strip. Detectable glucose concentrations ranged from 40 to 500 mg/dl.

The iSTAT POC analyzer<sup>h</sup> used in the study measured glucose concentration amperometrically. Oxidation of glucose by glucose oxidase produced hydrogen peroxide that was then oxidized at the electrode to produce a current proportional to glucose concentration of the sample. Detectable glucose concentrations ranged from 20 to 450 mg/dl.

Blood glucose concentration was also measured by use of Chemstrip color test strips.<sup>i</sup> These strips used a glucose oxidase-catalyzed reaction. Blood was manually wiped from the strip, and the test pad was visually compared to a color chart that contained colors corresponding to glucose concentrations of 20, 40, 80, 120, 180, 240, 400, and 800 mg/dl. Glucose concentration in the test sample was estimated as the closest color match.

All 110 blood samples were tested with the Glucofilm, Accu-Chek, and Elite meters and the iSTAT POC analyzer. One hundred six samples were tested with the Encore meter, 108 were tested with the ExacTech meter, and 39 were tested with Chemstrip test strips.

**Data analyses**—For purposes of statistical analyses, values reported "low" or "high" by a PBGM meter or the iSTAT analyzer were excluded, because these values could not be compared with the reference method value.

To determine the effect of using fresh versus anticoagulated blood on results obtained with the PBGM, a sign test<sup>3</sup> was used to compare concentrations obtained using fresh blood with concentrations obtained using anticoagulated blood. In addition, a sign test was used to compare absolute differences between concentrations obtained using fresh blood and reference method values with absolute differences between concentrations obtained using anticoagulated blood and reference method values, to determine whether fresh or anticoagulated blood yielded values closer to the reference method values.

To determine accuracy of the 5 PBGM, the iSTAT analyzer, and the Chemstrip test strip, linear regression models of values for each of these methods versus reference method values were constructed.<sup>3</sup> General linear tests were used to determine whether the slope of the regression line was different from 1 and the intercept was different from 0. Values of  $P < 0.05$  were considered significant. Values obtained with the reference method were also compared with values obtained for each of the other methods, using the sign test. Analyses were performed separately for samples with reference method concentrations < 100 mg/dl, concentrations

between 100 and 250 mg/dl, and concentrations > 250 mg/dl, and for all samples analyzed.

Ease of use of the various methods was evaluated subjectively. Percentage of times a clinical treatment decision would have been altered if results of each of these methods had been used, rather than results of the reference method, was calculated. Subjective clinical opinions of the authors were used to determine whether treatment would have been altered (eg, it was concluded that the clinical treatment decision would have been altered if blood glucose concentration for a diabetic dog was reported as < 100 mg/dl by the PBGM when the reference method value was > 100 mg/dl, because insulin dosage would have been inappropriately decreased in this dog if a clinician relied on results of the PBGM). Finally, for each method, percentage of results within 15% of the reference method value was determined.

## Results

**Comparison of fresh versus anticoagulated blood**—For the Glucofilm, ExacTech, and Elite meters, blood glucose concentrations obtained with fresh blood were not significantly different from concentrations obtained with blood samples anticoagulated with lithium heparin. For the Encore and Accu-Chek meters, concentrations obtained with fresh blood were significantly ( $P = 0.002$  and  $0.001$ , respectively) different from concentrations obtained with anticoagulated blood. The Encore meter was the only meter found to yield results for fresh blood samples that were significantly ( $P = 0.012$ ) closer to reference method values than results for anticoagulated blood samples. For this meter, mean absolute difference between concentrations obtained using fresh blood and reference method values was 7.9 mg/dl less than the mean absolute difference between concentrations obtained using anticoagulated blood and reference method values.

**Accuracy of blood glucose concentration determinations**—When linear regression models of results for all samples tested versus reference method values were examined, the null hypotheses that slope of the regression line equaled 1 and the intercept equaled 0 were rejected for 4 of the 5 PBGM, the iSTAT analyzer, and the Chemstrip test strips (Fig 1). The null hypotheses were accepted ( $P = 0.443$ ) only for the Elite meter. Coefficients of determination ( $r^2$ ) ranged from 0.82 to 0.99.

Because a minimal number of important data points can greatly alter the slope and intercept of a regression model, and because performance of various methods of determining blood glucose concentrations may vary with glucose concentrations of the samples used, we elected to construct regression models for each method for samples with reference method concentrations < 100 mg/dl, for samples with reference method concentrations between 100 and 250 mg/dl, and for samples with reference method concentrations > 250 mg/dl. The iSTAT analyzer had the highest coefficients of determinations for samples in each of these ranges ( $r^2 = 0.78$ ,  $0.92$ , and  $0.93$ , respectively) and for all samples considered together ( $0.99$ ). When linear regression models of results for samples with concentrations < 100 mg/dl versus reference method values were examined, the null hypotheses that slope of the regression line equaled 1 and the intercept equaled 0 were rejected for all 5 PBGM, the iSTAT analyzer, and the Chemstrip test strips; coefficients of determination ranged from 0.05 to 0.78. When samples with concentrations between 100 and 250 mg/dl were considered, the null hypotheses were rejected for all methods except the iSTAT analyzer; coefficients of determination ranged from 0.47 to 0.92. When samples with glucose concentrations > 250 mg/dl were considered, the null hypotheses were rejected for all methods except

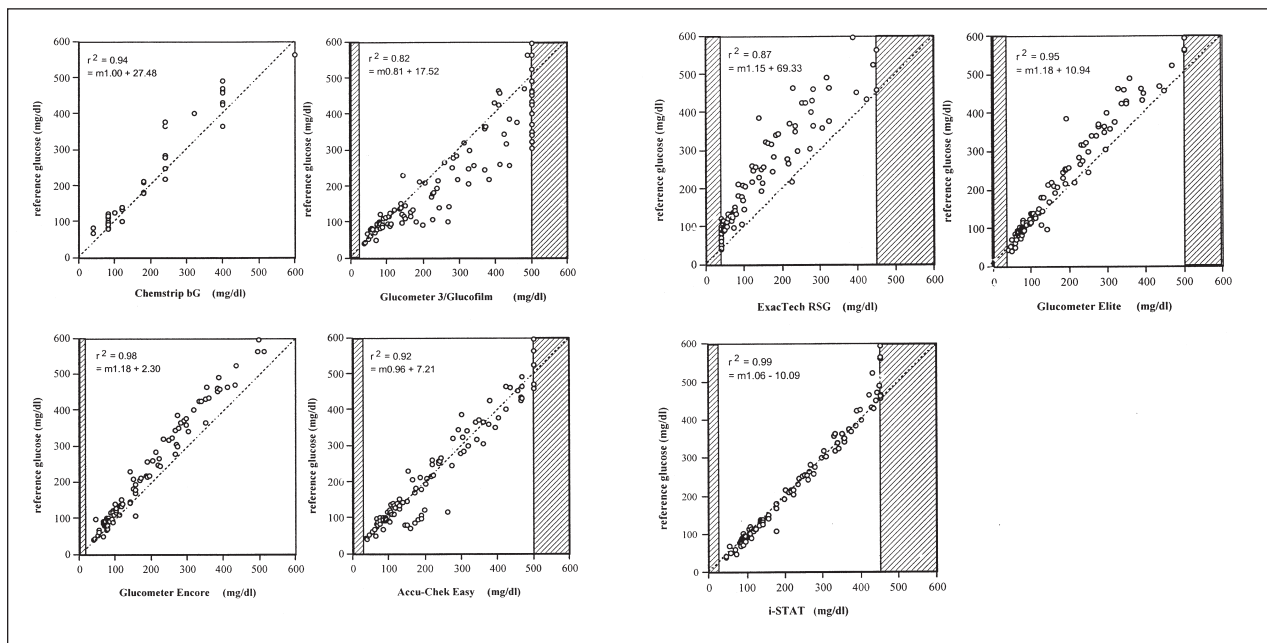


Figure 1—Scatter plots of blood glucose concentrations obtained with a color test strip (Chemstrip bG), 5 portable blood glucose meters, or a point-of-care analyzer (iSTAT) versus concentrations obtained using a reference method. Data represent 110 blood samples from 34 dogs. Shaded areas represent concentrations greater than or less than the concentrations that can be detected by each meter. The dashed line represents the theoretical line of equality.

Table 1—Deviance of blood glucose concentrations obtained with a color test strip (Chemstrip bG), 5 portable blood glucose meters, and a point-of-care analyzer (iSTAT) from concentrations obtained with a reference method and percentages of samples for which clinical treatment decisions would be altered by relying on results from these devices

Device (n)	Deviation from reference method value (range; mg/dl)	Percentage of samples within 15% of reference method value	Percentage of altered clinical treatment decisions
Chemstrip bG (39)	-136 to +37	68	13
Glucometer Glucofilm (110)	-95 to +196	53	17
Glucometer Encore (106)	-114 to +49	49	8
Accu-Chek Easy (110)	-87 to +144	74	9
ExacTech RSG (108)	-247 to +8	13	67
Glucometer Elite (110)	-193 to +43	31	15
iSTAT analyzer (110)	-94 to +69	99	0

the Glucofilm meter; however, the coefficient of determination for this meter for samples with concentration > 250 mg/dl was only 0.41. Coefficients of determination for the other devices ranged from 0.60 to 0.93.

**Ease of use**—All methods were simple to use, but individual features made some methods easier than others. The Chemstrip test strips were simple to use but required visual comparison of results with a color chart, which may be problematic depending on the tester's eyesight and color acuity. It was difficult to remove test strips for the ExacTech and Elite meters from their packaging without touching them improperly. Neatly loading the appropriate amount of blood onto the test strips was difficult for the Encore and ExacTech meters. Problems with wiping blood off test strips or loading strips into the meter were common for the Glucofilm and Encore meters. Some meters, particularly the ExacTech, displayed results for only a brief period. Overall, we found the Accu-Chek easiest to use and the Encore most complicated.

**Alterations in treatment decisions**—For each of the methods, individual samples yielded results higher or lower than the reference method value (Table 1). In most instances, these differences would not have changed therapeutic decisions, particularly for samples with high glucose concentrations. However, for several samples, reliance on results of the Chemstrip test strip or one of the PBGM, instead of results of the reference method, would have resulted in an alteration of a clinical decision. Alterations in treatment decisions were particularly likely when reference glucose concentration, the glucose concentration obtained with either the Chemstrip test strip or the PBGM, or both, were less than or approximately 100 mg/dl.

**Agreement with reference method value**—The PBGM and the Chemstrip test strip frequently yielded results 15% greater or less than the reference method value (Table 1), even after excluding samples for which results of the PBGM were recorded as "high" or "low." The ExacTech meter produced results within 15% of reference method value only 13% of the time. On the other hand, results from the iSTAT analyzer were within 15% of the reference method value 99% of the time.

## Discussion

Portable blood glucose meters and POC analyzers are being used with greater frequency by veterinarians.

These PBGM devices offer several advantages over standard automated analyzers used by diagnostic laboratories. They are small and portable, require use of only small quantities of blood, and provide results rapidly. The low cost and ready availability of these devices add to their attractiveness. However, because results obtained with these devices will often dictate the course of clinical care, it is important that the devices provide accurate information.

In the present study, we found large differences in reliability of results, and results for the Chemstrip test strips were as reliable as results of any of the PBGM. Although the correlation between results of the PBGM, the iSTAT analyzer, and the Chemstrip test strips and results of the reference method for the entire range of blood glucose concentrations was always > 82%, this type of statistical testing may not provide a complete picture. The correlation coefficient measures the strength of association between 2 variables, not the strength of agreement. Perfect correlation between 2 variables will be obtained if data points for 1 variable versus the other fall along any straight line, but perfect agreement will be obtained only if all data points lie along the line of equality. Over the entire range of values, only the Elite meter yielded values that statistically were considered to lie along the line of equality; however, results for this meter did not lie along the line of equality when subsets of the samples were analyzed. On the other hand, the iSTAT analyzer, which performed best for most subsets of samples, did not yield results that lay along the line of equality when the entire range of samples was considered. This was largely because of discrepancies in a few crucial data points at high glucose concentrations and because of the limited variability of the data for the iSTAT analyzer. Although the PBGM were expected to perform best on samples with glucose concentrations in the reference range, rather than on samples with high or low glucose concentrations, for several devices, results for samples with glucose concentrations > 250 mg/dl were more highly correlated with reference method values than results for samples with glucose concentrations between 100 and 250 mg/dl.

Determination of the percentage of results within 15% of the reference method value provided another clinically relevant means to evaluate these methods of measuring blood glucose concentration. For samples with higher glucose concentrations, a larger absolute difference between the true glucose concentration (ie,

the reference method value) and the measured concentration can be tolerated without jeopardizing the well-being of the patient. A consensus statement from the American Diabetes Association and the National Institutes of Health suggests that results from devices used to self-monitor blood glucose concentrations in people should fall within 15% of results of an established reference method for the device to be clinically useful.<sup>2</sup> On this basis, the only method tested in the present study that would have been considered acceptable was the iSTAT analyzer. Three of the PBGM yielded results within 15% of the reference method value less than half the time.

Results from the methods tested in the present study would have frequently caused a clinician to alter clinical treatment decisions. Samples that were markedly hyperglycemic (reference method concentration > 250 mg/dl) were generally reported as hyperglycemic by all other methods used, and clinical treatment decisions would probably not have been altered even if the difference between the reference method value and the measured value was > 15%. However, discrepancies for samples with lower glucose concentrations were more important. In particular, these devices often yielded results lower than the reference method concentrations. Although this may help human patients with diabetes mellitus who are self-monitoring blood glucose concentrations avoid hypoglycemia, it may lead to inappropriate decisions when using results to determine adjustments to insulin dosage. The ExacTech meter was particularly prone to giving results lower than the reference method values that would have resulted in inappropriate reductions in insulin dosage. Clinically, the most important errors would be those in which 1 of these devices indicated euglycemia when the true glucose concentration was low. Although the Glucofilm meter was subject to providing results higher than the true concentration, differences were not as severe at lower glucose concentrations as they were at higher concentrations.

There are many potential sources of error in determination of blood glucose concentration, and these sources may vary slightly from 1 device to another. Potential sources include operator error, environmental or sample factors, and machine error. Operator errors would include improper machine calibration, use of outdated reagent strips, timing errors, improper wiping of blood, improper blood droplet size or placement, or improper sample insertion. Temperature, altitude, and humidity can all influence results,<sup>4,5</sup> as can sample factors such as patient temperature, patient hematocrit, oxygen tension, and plasma concentrations of substances such as triglyceride, creatinine, uric acid, ascorbic acid, and proteins.<sup>4,7</sup> Although we did not control these factors in the present study, we did simulate the situation in which most veterinarians would use these devices in practice. Because we tested only 1 of each brand of device, it is possible that another individual device of the same type would have pro-

vided more or less accuracy than the individual devices we tested.

The PBGM and the Chemstrip test strips used in this study were designed to facilitate monitoring of blood glucose concentrations in human patients with diabetes mellitus. Therefore, they were generally designed for use with capillary blood obtained with a lancet. Because of difficulties in obtaining capillary samples from dogs, most veterinarians use venous blood in these devices. Although the manufacturer of the Accu-Chek meter specifically stated that venous blood should not be used, manufacturers of the Chemstrip test strips and the other 4 PBGM stated that venous blood could be used, and the manufacturer of the iSTAT analyzer stated that venous blood was preferred. Because of the chemical properties of some test strips, use of venous blood will yield higher than expected results,<sup>7</sup> and some manufacturers provide estimated correction factors for results obtained when using serum or plasma rather than blood. In patients who have not eaten recently, capillary blood glucose concentration is expected to be 2 to 5 mg/dl higher than the venous blood glucose concentration. After a meal, however, the difference can be as much as 20 to 70 mg/dl.<sup>7</sup> This may have practical implications in veterinary medicine, because blood glucose concentrations are often measured in dogs that have eaten recently. In fact, a common use of these devices in veterinary medicine is determining changes in glucose concentration in response to insulin, a situation in which dogs are expected to be fed.

<sup>a</sup>Microtainer, Becton-Dickinson, Franklin Lakes, NJ.

<sup>b</sup>Vitros 500, Ortho-Clinical Diagnostics, Rochester, NY.

<sup>c</sup>Glucometer 3/Glucofilm, Bayer Corp, Elkhart, Ind.

<sup>d</sup>Glucometer Encore, Bayer Corp, Elkhart, Ind.

<sup>e</sup>Accu-Chek Easy, Boehringer, Mannheim, Indianapolis, Ind.

<sup>f</sup>ExacTech RSG, MediSense Inc, Waltham, Mass.

<sup>g</sup>Glucometer Elite, Bayer Corp, Elkhart, Ind.

<sup>h</sup>iSTAT analyzer, Heska Sensor Devices, Waukesha, Wis.

<sup>i</sup>Chemstrip bG, Boehringer, Mannheim, Indianapolis, Ind.

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