ABSTRACT  Effects of rapid postmortem metabolism and delayed chilling on turkey breast meat quality were assessed using color measurements, protein extractability, and gelation characteristics. Based on 15 min postmortem breast muscle pH, tom turkey carcasses were classified as rapid glycolyzing (RG), pH ≤ 5.80, or normal glycolyzing (NG), pH > 6.00. Two carcasses per group with similar ultimate pH values were selected on four occasions for a total of 16 carcasses. One half of each carcass was immersion-chilled at 20 min postmortem, the other half was maintained at body temperature for 110 min and then chilled. Breast meat from RG carcasses had higher carcass temperature (15 min) and lower protein (sarcoplasmic and myofibrillar) extractability than breast meat from NG carcasses. Delayed chilling increased all breast meat color values (L*, a*, b*), and decreased protein extractability and cook yield compared to breast meat from immediately chilled carcass halves. The true strain of cooked gels was reduced for RG carcasses. Delayed chilling reduced both true strain and stress of meat gels. There were no interactions between the rate of postmortem pH decline and initiation of chilling, indicating that reductions in meat quality due to delayed chilling were independent of the carcass classification for rate of postmortem glycolysis. Results indicate that factors that affect both rate of postmortem glycolysis and carcass temperature decline are important to turkey breast meat quality.

(Key words: turkey meat, breast meat quality, color, rigor mortis development, chilling)
Fernandez et al. (1994) subjected pork to different rates of chilling and found a reduction in water- and salt-soluble protein extraction for the slower rates of chilling. This effect was diminished in carcasses with higher ultimate pH (pHult) values, indicating that there is an important relationship between pH and temperature of muscle during the early period of chilling. These contradictory results for the effects of decreased chilling rates on protein extractability between species may indicate that turkey breast muscle responds differently to elevated postmortem temperatures than pork. It is important to understand the influence of chilling rates on turkey breast quality because selection pressure to increase size of turkey breeds continues. Selection for increased growth rate and muscle size of the modern turkey have resulted in a 27% heavier carcass at 18 wk of age than turkey toms from 1985 (Sell, 1995). These larger carcasses require more time to reduce internal muscle temperature in immersion chilling systems, thus postmortem time at elevated temperatures has increased.

In the meat industry, a quick nondestructive method to evaluate product quality is an extremely valuable tool. Investigations have been conducted into the use of color measurements to screen for PSE pork carcasses (Roseiro et al., 1994). Barbut (1993, 1996a) reported that “PSE turkey breast” had higher L* value readings (lighter) than normal breast; however, rate of glycolysis was not determined. Additionally, L* values were negatively correlated with breast meat pHult. Ultimate pH can influence properties such as protein extractability, cook yield, and stress and strain of cooked gels (Daum-Thunberg et al., 1992). Pietrzak et al. (1997) reported higher L* values for breast meat from RG carcasses than for breast meat from normal glycolyzing (NG) carcasses. However, pHult was lower for breast meat from RG carcasses. Thus, in a number of studies, rate of pH decline and different pHult may confound any findings.

The problem of low quality turkey breast meat is often observed in the manufacture of oven-cooked products (Ferket, 1995). There are no reports regarding the combination of a rapid rate of postmortem glycolysis and increased time at elevated carcass temperatures on quality of processed turkey breast products. In the following experiments, RG and NG turkey carcasses of similar pHult values were selected. Chilling was delayed for one half of each carcass, and the other half was chilled immediately following pH measurements. The objective was to determine the effects of rapid postmortem glycolysis and a delay in chilling on color of raw turkey breast muscle and the quality of this muscle for use in processed products. A secondary objective was to determine whether delaying chilling was more detrimental to quality of RG turkey breast than NG breast meat.

**MATERIALS AND METHODS**

**Sample Preparation**

Tom turkey carcasses weighing 10.5 to 12 kg were removed from the processing line in a commercial slaughter plant at 15 min postmortem for pH measurements. Two groups of carcasses were selected based on triplicate pH readings. A model HI9025 portable pH meter equipped with a spear tip electrode was inserted into the P. major at the edge of the feather tract directly ventral to the wing joint. Carcasses with a 15-min postmortem pH ≤ 5.80 were classified as RG and carcasses with a 15-min postmortem pH > 6.00 were classified as NG. The temperature of all carcasses was taken at 15 min postmortem next to the location of pH measurement. A minimum of two birds from each group were obtained on 4 separate d.

Following rate of rigor classification, carcasses were split in half through the spine and center of the keel with a hand held meat saw to obtain a left and right side. Any damage to muscle tissue was noted for later reference. At 20 min postmortem, one side was chosen at random and placed in a static ice water bath. The other side was placed in a 40-L styrofoam box containing a filled 2-L hot water bottle (40 ± 2 C). At 110 min postmortem, the side in the insulated box was transferred to the ice water bath. Carcass halves were chilled for a total of 60 min in the static ice water slush and packed in ice in insulated boxes. The boxes containing the carcasses were transferred to a cooler (0 ± 2 C), held overnight and transported to the University of Saskatchewan. Temperature of the center of the Pectoralis major was monitored in two carcass halves each day from 15 min postmortem for 18 to 24 h with temperature tracking devices (TempTale3, 4 ICON Data Logger).

At 18 to 24 h postmortem the P. major was removed from each carcass half. The exterior surface of each breast sample was removed to a depth of 1 cm to avoid inclusion of skin damage due to exposure to extreme temperatures during the scalding procedure. Areas of tissue damage from splitting the carcass in half were also trimmed. The breast fillets were placed into plastic bags and stored overnight at -1 C. At 36 h postmortem, the breast samples were ground through a 20-mm plate followed by a 3-mm plate (4 C equipment), mixed, and held at 2 to 4 C until used.

**Color**

A sample of each ground breast was firmly pressed into a plastic disposable Petri dish (diameter 5.3 cm, depth 1 cm) and stored in the dark at 4 C. Fifty min after grinding...
the color of the sample was determined in duplicate with a Hunter Associates Laboratories Inc., Reston, VA 20190.

A reader would need to understand the context and the biological processes described, which are not apparent from the image.
TABLE 1. Carcass temperature, ultimate pH, and color measurements of normal and rapid glycolyzing turkey breast and the effect of delaying the chilling procedure 90 min.

<table>
<thead>
<tr>
<th>Source</th>
<th>Carcass temperature 15 min postmortem</th>
<th>Ultimate pH</th>
<th>L*</th>
<th>a*</th>
<th>b*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rate of postmortem glycolysis</td>
<td></td>
<td>(C)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NG1</td>
<td>43.9b</td>
<td>5.71a</td>
<td>52.01a</td>
<td>15.66a</td>
<td>14.02a</td>
</tr>
<tr>
<td>RG2</td>
<td>44.5a</td>
<td>5.67a</td>
<td>51.86a</td>
<td>17.04a</td>
<td>14.90a</td>
</tr>
<tr>
<td>SEM (n = 8)</td>
<td>0.15</td>
<td>0.02</td>
<td>0.54</td>
<td>0.46</td>
<td>0.42</td>
</tr>
<tr>
<td>Start of immersion chilling</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 min postmortem</td>
<td>5.73a</td>
<td>51.06b</td>
<td>15.80b</td>
<td>13.68b</td>
<td></td>
</tr>
<tr>
<td>110 min postmortem</td>
<td>5.65b</td>
<td>52.81a</td>
<td>16.90a</td>
<td>15.23a</td>
<td></td>
</tr>
<tr>
<td>SEM (n = 16)</td>
<td>0.01</td>
<td>0.19</td>
<td>0.20</td>
<td>0.23</td>
<td></td>
</tr>
</tbody>
</table>

Means in a column within a treatment group with no common superscript differ significantly (P < 0.05).

1NG = normal glycolyzing (pH > 6.00 at 15 min postmortem).
2RG = rapid glycolyzing (pH ≤ 5.80 at 15 min postmortem).

cylinders as possible (~12 per sample). Cyanoacrylate glue (Loctite 40413) was used to attach styrene discs to each end of the cut samples. These samples were milled into capstan-shapes with a center diameter of 10 mm using a modified bench grinder. Following shaping the samples were twisted to fracture at 2.5 rpm on a torsion Gelometer according to methods described by Kim et al. (1986). The shear stress and true shear strain at fracture were determined using software that calculates these on the basis of torque and angular displacement (Hamann, 1983).

**RESULTS AND DISCUSSION**

For the measurements made in this study there were no interactions found between rate of pH decline and carcass chilling rate. Therefore, only differences between main effects will be discussed.

**Carcass Temperature**

Carcasses selected as RG based on low 15 min postmortem pH values were found to have a significantly higher (P < 0.05) carcass temperature at 15 min postmortem than NG carcasses (Table 1). Studies involving pork have made similar findings in which early postmortem temperature for PSE pork was higher than for normal pork due to heat generated by accelerated metabolism (Offer, 1991).

The difference in temperature decline between carcass halves immediately immersion chilled and halves delayed chilled are readily apparent in Figure 1. The average

**Statistical Analysis**

Means for each attribute were computed and analyzed as a split-plot design using the General Linear Models procedure (SAS Institute, 1990). The rate of rigor development was the main plot treatment with the comparison of chilling immediately vs delayed chilling as a subplot treatment. Slaughter dates were the blocks in the experiment. There were two carcasses per treatment per block. The subsampling terms were tested against the appropriate interactions with block to determine whether these terms were significantly different from each other and whether it was appropriate to combine them for the error terms. The interaction with block and rate of rigor development was combined with the subsampling term (two birds per treatment per block) to create the error term for testing main plot effects. The interaction with blocks and chilling rate as well as the three way interaction with blocks, rate of rigor development, and chilling rate were combined with the subsampling term to form the error for testing subplot effects.

13Loctite Corp., Mississauga, ON, Canada, L4Z 1S6.
14Gel Consultants Inc., Raleigh, NC 27612-3031.
temperature at the center of the breast muscle following the 90 min delay in chilling was 39.8 ± 1.2 C. Following 90 min in the insulated box, the rate of temperature decline for the delay chilled carcass halves was the same as halves which were immediately chilled. The average breast temperature for delayed and immediately chilled carcass halves after 60 min of chilling was 20.4 ± 2.7 C and 21.5 ± 3.2 C, respectively.

**Muscle pH and Color**

The pH\textsubscript{ult} values of the breast meat from the RG carcasses were not different from those of the NG carcasses (Table 1). One of the goals of this study was to evaluate the effects of the rate of pH decline without the influence of differences in pH\textsubscript{ult}. This goal was achieved by excluding carcasses with extreme pH\textsubscript{ult} values from each block. However, delaying the chilling procedure for one half of the carcass did reduce the pH\textsubscript{ult} (pH difference = 0.08) compared to halves chilled immediately.

Breast meat color was not affected by rate of postmortem glycolysis (Table 1). However, there was a trend (P = 0.055) for breast meat from RG carcasses to have higher a* values than NG samples. Several researchers have reported color changes in turkey breast meat that underwent an accelerated rate of postmortem glycolysis (Froning et al., 1978; McKee and Sams, 1997; Pietrzak et al., 1997). Froning et al. (1978) reported lower L* values and higher a* values for breast meat from heat-stressed or free struggling turkeys than the control birds. Pietrzak et al. (1997) found higher L* values for turkey breast meat designated PSE based on 20 min postmortem pH values of less than 5.8 compared to normal meat (pH > 5.8), but no differences in a* values were found. McKee and Sams (1997) reported increased L* values for breast meat from turkey toms exposed to high temperatures (38/32 C: day/night) for the last 4 wk of life compared to control birds kept at cooler temperatures.

It is difficult to determine whether increases in L* value in the studies by Pietrzak et al. (1997) and McKee and Sams (1997) are due to accelerated postmortem glycolysis or to differences in pH\textsubscript{ult} or both. The average pH\textsubscript{ult} for PSE breast meat in the study by Pietrzak et al. (1997) was 0.19 units lower than for their normal meat. The pH\textsubscript{ult} for breast meat from heat-stressed birds in the study by McKee and Sams (1997) was 0.10 units lower than for unstressed birds. A significant negative correlation between L* values and pH\textsubscript{ult} has been reported for turkey breast (Barbut 1993, 1996a) and meat from other animals such as cattle (MacDougall and Rhodes, 1972).

Breast meat from delay chilled carcasses was significantly lighter (higher L*), redder (higher a*), and yellower (higher b*) than comparable samples from carcass halves chilled immediately (Table 1). McKee and Sams (1998) reported increased L* values for turkey breast held at 40 C for 2 h compared to samples held at lower temperatures (20 and 0 C).

Reasons for these changes in color with delays in chilling are unclear. The difference in pH\textsubscript{ult} of 0.08 units may contribute to lighter meat. In a study by Cornforth and Egbert (1985) all three color values increased when prerigor beef was acidified with 0.2 M citrate buffer, pH 5.3, or when rotenone was added. Rotenone inhibits activity of mitochondria, allowing myoglobin to remain oxygenated, and treated meat to appear a brighter red (Cornforth and Egbert, 1985). Mitochondria from PSE pork show considerable disruption and have an open-structured appearance (Dutson et al., 1974). If mitochondrial activity in turkey breast meat from carcasses proceeding through rigor at an accelerated rate was reduced, there would be less competition with myoglobin for oxygen after grinding and the meat would appear redder.

**Protein Extractability**

Extractability of both sarcoplasmic (SP) and myofibrillar proteins (MP) from breast meat of RG turkey carcasses was reduced compared to NG carcasses (Table 2). Sarcoplasmic protein extractability was slightly lower in RG carcasses than NG carcasses. The difference in MP extractability between NG and RG carcasses was much larger than it was for SP, with 50% more MP being extracted from NG carcasses than from RG carcasses. Lopez-Bote et al. (1989) found MP extractability was reduced to a greater extent than SP extractability in PSE pork. Boles et al. (1992) found similar results for stress susceptible swine. Northcutt (1994) selected pale and normal colored turkey breast with the same pH\textsubscript{ult} and found no difference in total (SP+MP) protein extractability. There are no previously published results for protein extractability differences between RG and NG turkey breast.

Delayed chilling of carcasses reduced SP and MP extractability to the same degree as increased rate of rigor development (Table 2). Fernandez et al. (1994) subjected pork to different rates of chilling and found a reduction in water- and salt-soluble protein extraction when the chilling procedure was slower. As pH\textsubscript{ult} increased the effect of slower chilling rates on protein extractability diminished.

Lesiak et al. (1996) removed breast muscle strips immediately postmortem from normal glycolyzing turkey toms and held them at 30 C for 15 and 240 min. They found that holding muscle strips at 30 C increased the protein extractability compared to strips held at 0 C. Differences in sample preparation (muscle strip vs intact muscle), treatment temperatures, and protein extractability procedures may all contribute to these contrasting findings.

**Cook Yield and Expressible Moisture**

Rate of glycolysis had no effect on cook yield or expressible moisture of cooked meat gels. Pietrzak et al. (1997) reported a decrease in cook yield for ground RG
TABLE 2. Protein extractability, water holding capacity, and rheology of cooked gels from normal and rapid glycolyzing turkey breast and the effect of delaying the chilling procedure 90 min

<table>
<thead>
<tr>
<th>Source</th>
<th>Extractable sarcoplasmic proteins</th>
<th>Extractable myofibrillar proteins</th>
<th>Cook yield</th>
<th>Expressible moisture</th>
<th>Stress</th>
<th>True strain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rate of postmortem glycolysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NG1</td>
<td>29.9a</td>
<td>14.6a</td>
<td>90.6a</td>
<td>20.3a</td>
<td>37.47a</td>
<td>1.43a</td>
</tr>
<tr>
<td>RG2</td>
<td>27.7b</td>
<td>9.7b</td>
<td>88.2a</td>
<td>20.5b</td>
<td>34.83b</td>
<td>1.27b</td>
</tr>
<tr>
<td>SEM (n = 8)</td>
<td>0.59</td>
<td>1.11</td>
<td>0.91</td>
<td>0.88</td>
<td>1.80</td>
<td>0.04</td>
</tr>
<tr>
<td>Start of immersion chilling, min postmortem</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>29.5a</td>
<td>14.4a</td>
<td>91.0a</td>
<td>20.1a</td>
<td>37.99a</td>
<td>1.45a</td>
</tr>
<tr>
<td>110</td>
<td>28.1b</td>
<td>9.9b</td>
<td>87.9b</td>
<td>20.8b</td>
<td>34.30b</td>
<td>1.25b</td>
</tr>
<tr>
<td>SEM (n = 16)</td>
<td>0.19</td>
<td>0.62</td>
<td>0.54</td>
<td>0.75</td>
<td>1.28</td>
<td>0.02</td>
</tr>
</tbody>
</table>

a,bMeans within a source and in the same column with no common superscript differ significantly (P < 0.05).

1NG = normal glycolyzing (pH > 6.00 at 15 min postmortem).
2RG = rapid glycolyzing (pH ≤ 5.80 at 15 min postmortem).
3Expressed as a percentage of total protein in the meat sample.
4Expressed as a percentage of raw batter weight.
5Expressed as a percentage of cooked gel weight.

turkey compared to NG turkey breast mixed in a solution of 2.5% NaCl and 0.04 M Na2HPO4 (1:3) heated to 80 °C; however, there was also a difference in pHult of 0.19, which may have been responsible for some of the observed decrease in cook yield. McCurdy et al. (1996) reported a significant negative correlation between pHult of minced turkey breast meat and cook loss.

Delaying the chilling procedure reduced cook yield but had no effect on expressible moisture. In the study by Lesiak et al. (1996), cook yield was reduced for turkey breast muscle strips held at 30 °C compared to 0 and 12 °C when water, salt, and phosphate were added to the sample; however, no differences were found for samples when only water was added.

**Torsion**

Torsion results indicate that structure of cooked meat gels was affected by differences in both rate of postmortem glycolysis and rate of chilling. The measurement of stress at fracture is a measure of gel hardness and is sensitive to changes in protein functionality, protein concentration, and thermal processing (Hamann, 1988). Stress values can be used to detect when fillers such as starch or denatured proteins are present in a gel prior to cooking. Strain is an indication of cohesiveness or functionality of proteins in the gel (Hamann, 1988). The stress at fracture was not different between gels from RG and NG carcasses. The strain values for RG breast meat gels were lower than gels made from NG meat (Table 2). This fact would suggest the proteins in RG breast meat formed a less cohesive gel than proteins from NG birds. No reports of differences between NG and RG turkey breast meat gels are available. However, Northcutt (1994) found no difference in stress and strain values between gels made from pale or normal colored turkey breast muscles with similar pHult. This finding emphasizes the importance of having a measure of rate of postmortem glycolysis to determine quality of breast meat.

Delaying the initiation of chilling reduced both stress and strain of turkey breast meat gels. The lower value for MP extractability would indicate that less protein would be available to form gels, resulting in a weaker gel. Changes to stress and strain would explain the poor texture reported for products made from pale soft turkey breast (Ferket, 1995). Camou and Sebranek (1991) produced gels from the salt-soluble protein extracts of normal and PSE pork. The gels were back extruded with a plunger attached to an Instron testing device. They reported that the strength of gels from PSE meat was 45% of that for gels from normal pork for the same protein concentration.

**Treatment Combination**

No interactions were detected for any measurements made between the rate of rigor mortis development and initiation of the chilling procedure. The practical significance of this is that a delay in carcass chilling produced deleterious effects on carcass quality regardless of how fast the pH was declining. Both rate of rigor and rate of temperature decline affected breast meat quality, a lack of interaction indicates the effects of rapid glycolysis and delayed chilling are additive. Therefore a delay in chilling would magnify problems already present due to a rapid rate of pH decline. For example, the MP extractability of immediately chilled NG carcass halves was more than twice that of RG carcass halves delay chilled. It is difficult to separate these two processes, as a reduced rate of chilling increases the rate of postmortem glycolysis (Greaser, 1986).
TABLE 3. Correlations (r values) of measurements from normal and rapid glycolyzing turkey breast including carcass halves chilled immediately and delayed 90 min from chilling

<table>
<thead>
<tr>
<th>Variable</th>
<th>Ultimate pH</th>
<th>Sarcoplasmic protein 1</th>
<th>Myofibrillar protein 2</th>
<th>Cook yield 3</th>
<th>Expressible moisture 4</th>
<th>Stress</th>
<th>Strain</th>
</tr>
</thead>
<tbody>
<tr>
<td>L*</td>
<td>-0.41**</td>
<td>-0.47**</td>
<td>-0.59***</td>
<td>-0.37*</td>
<td>NS</td>
<td>-0.45**</td>
<td>-0.61***</td>
</tr>
<tr>
<td>a*</td>
<td>NS</td>
<td>-0.68***</td>
<td>-0.55***</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>b*</td>
<td>-0.47**</td>
<td>-0.66***</td>
<td>-0.64***</td>
<td>-0.39*</td>
<td>NS</td>
<td>NS</td>
<td>-0.56***</td>
</tr>
<tr>
<td>Sarcoplasmic 1</td>
<td>0.54***</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Myofibrillar 2</td>
<td>0.67***</td>
<td>0.71***</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cook yield</td>
<td>0.63***</td>
<td>0.53**</td>
<td>0.78***</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expressible moisture 3</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>-0.72***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stress</td>
<td>0.69***</td>
<td>0.60***</td>
<td>0.81***</td>
<td>0.84***</td>
<td>NS</td>
<td></td>
<td>0.58***</td>
</tr>
<tr>
<td>Strain</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1Extractable sarcoplasmic proteins expressed as a percentage of total protein.
2Extractable myofibrillar proteins expressed as a percentage of total protein.
3Cook yield expressed as a percentage of the raw batter weight.
4Expressible moisture expressed as a percentage of cooked gel weight.

*P < 0.05.
**P < 0.01.
***P < 0.001.

Correlations

Correlations among pH, color, and meat quality measurements are listed in Table 3. In the present study, the L* value was not useful for predicting changes to meat quality due to differences in the rate of postmortem glycolysis. There are some significant correlations with other measurements; however, the r² values are less than 0.4, indicating that the statistical model does not explain a great deal of the variation. Barbut (1993, 1996a) reported significant correlations between L* value and pHult (r = -0.71 and -0.65 respectively) in investigations in which lightness values were used to screen for “PSE turkey breast”. They found that higher L* values also corresponded to breast meat with lower water holding capacity. Our results indicate that the correlation between L* value and pHult was not very meaningful, with an r value of only -0.41 (P < 0.01). These low correlation coefficients are likely due to the small range of pHult values. The lower water holding capacity values in Barbut’s (1993, 1996a) investigations may have been due to differences in pHult rather than anything related to the rate of postmortem pH decline, as rate of glycolysis was not determined.

Significant correlations with pHult included, b*, SP and MP extractability, cook yield, and true strain. However, most of these correlations were very low. Some higher correlations were between MP extractability, cook yield, and true strain. These positive correlations indicated that as MP extractability increased, cook yield, and strain of breast meat gels also increased. Myofibrillar protein extractability was a better predictor of gel cohesiveness than any color measurement.

Conclusions

Results of this study indicate that both rapid postmortem glycolysis and a delay in the reduction of carcass temperature result in turkey breast meat with reduced ability to hold water and form stable cooked gels. The fact that these effects were of an additive nature indicates that improvements to turkey breast meat quality may be achieved by focusing on either parameter. Factors that influence the rate of postmortem glycolysis need to be addressed to determine feasible changes to production procedures which will impact meat quality. Minimizing processing line stoppages and maximizing carcass cooling rates may result in improvements in meat quality when poor carcass cooling occurs.

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